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FEBRUARY 1977
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Navigation Systems

ST. MARYS RIVER COGLAD NAVIGATION SYSTEM FINAL REPORT

Prepared by

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A short baseline Loran-C (mini-Loran) chain has been installed by the Coast Guard to facilitate ore-boat traffic between Lake Superior and Lake Huron via the St. Marys River. A Coast Guard Loran Assist Device (COGLAD), previously developed by the Applied Physics Laboratory, The Johns Hopkins University, was modified for shipboard evaluation aboard Coast Guard vessels on the St. Marys River. This report ~~xxx~~ discusses the COGLAD hardware and software modifications, way-point survey data, operating procedure, test results, and recommendations.

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- Surface navigation

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- Course indicators
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ABSTRACT

A short baseline Loran-C (mini-Loran) chain has been installed by the Coast Guard to facilitate ore-boat traffic between Lake Superior and Lake Huron via the St. Marys River. A Coast Guard Loran Assist Device (COGLAD), previously developed by the Applied Physics Laboratory, The Johns Hopkins University, was modified for shipboard evaluation aboard Coast Guard vessels on the St. Marys River. This report discusses the COGLAD hardware and software modifications, way-point survey data, operating procedures, test results, and recommendations.

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CONTENTS

ILLUSTRATIONS

TABLES

1. INTRODUCTION

1.1 DEFINITION OF THE PROBLEM

The St. Marys River forms part of the U.S./Canadian border and links Lake Superior and Lake Huron (Fig. 1). Throughout much of the 65 miles of the river, large vessels (up to 1000 ft in length and 105 ft in beam) are confined to dredged channels no more than 300 ft in width.* To facilitate handling the large volume of traffic, the Coast Guard maintains an extensive array of buoys, day beacons, and visual ranges, as well as a radio vessel-reporting system. However, during the winter months, additional aids to navigation are needed to compensate for frequent poor visibility, buoys removed or pushed under the ice, and confusing radar returns because of ice ridges. Navigational aids such as a laser reflector system and a high-resolution radar system were tried unsuccessfully before the installation of a Loran-C minichain.

The St. Marys River minichain is functionally identical to a conventional Loran-C chain except that it has shorter baselines (i.e., the transmitters are closer together) and uses lower power transmitters. Four transmitters are used, two in Michigan and two in Canada. The short baselines assure good time-difference geometry and signal strength within the coverage area. The design goal stated by the Coast Guard was to determine a boat's cross-track position (left or right of channel) with an accuracy of ±25 ft for 95% of the time. Beyond the design coverage area, the accuracy degrades rapidly because of poor geometry, and the minichain should be used only in the immediate vicinity of the St. Marys River.

In the art of piloting, the most meaningful position information is position relative to a known point, an intermediate way point, or a final destination. The entire St. Marys River from Whitefish Bay to De Tour Passage can be described as a series of 25 to 28 straight-line segments where each segment is the centerline of its respective channel. The point where the centerlines of two adjacent channels intersect has been defined as an intermediate way point. Each of these way points has been numbered and the Loran coordinates surveyed. By storing the Loran coordinates in the extended memory of the Coast Guard Loran Assist Device (COGLAD) system, continuous navigation guidance can be provided throughout the entire St. Marys River relative to known points.

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*By convention, distances in the Great Lakes are given in terms of statute miles (mi). For this reason, statute miles and feet are used throughout this report.

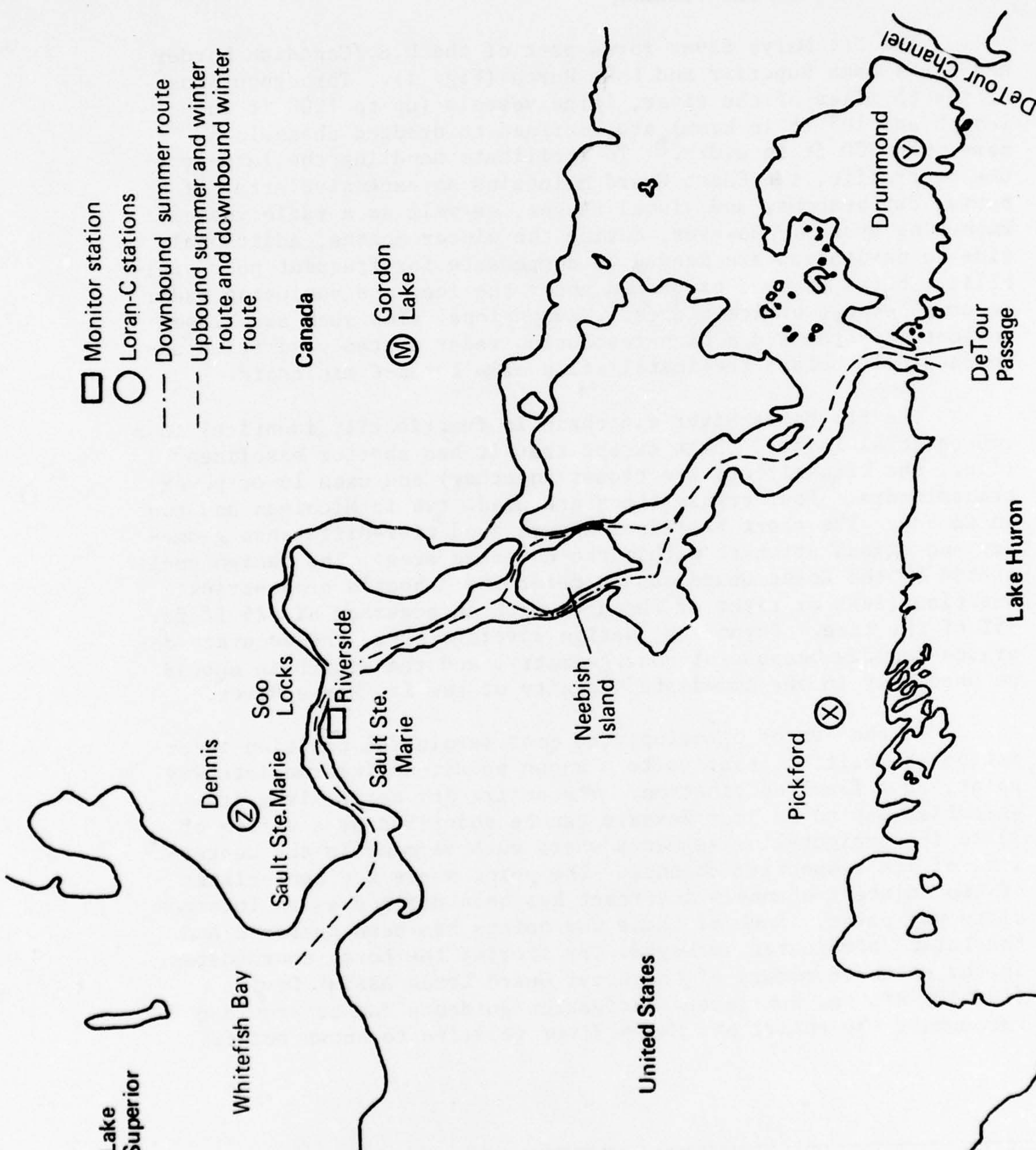

Fig. 1 The St. Marys River

The Applied Physics Laboratory (APL) conducted a two-part program to modify and field test an existing COGLAD for use as an aid to piloting ore carriers between Lake Superior and Lake Huron via the St. Marys River. The first part, Task 1, covered the modification of the COGLAD furnished by the Coast Guard. The final part, Task 2, covered field operations conducted aboard Coast Guard vessels.

Task 1 of the St. Marys River COGLAD program included developing (a) a new bridge display with neon bar graphs, (b) a system of way points for upbound and downbound channels, and (c) extensive new software including stored way points, erroneous time difference rejection, and automatic dead reckoning. At the request of the Coast Guard, APL rack mounted the COGLAD equipment to facilitate shipboard installation. The equipment was shipped to the Coast Guard base at Sault Ste. Marie, Michigan, on 21 November 1975.

Task 2 of the program consisted of system calibration and verification, and a system demonstration performed primarily aboard the Coast Guard cutter Naugatuck. The field work was conducted from January through July 1976. During that time the entire river was surveyed, and the Loran coordinates were measured to enable navigation of the river.

1.2 COGLAD NAVIGATION EQUIPMENT

In 1967, APL developed a Loran Assist Device (LAD) for a classified military operation requiring precision aircraft guidance. Since then, APL has developed a number of newer and more sophisticated versions of the original LAD. In 1970, the Coast Guard funded APL to develop a version for civilian use that became known as the Coast Guard Loran Assist Device, or COGLAD. Two COGLAD systems were eventually built for the Coast Guard and have been used experimentally for positioning buoys in Lake Huron, ice patrols in the North Atlantic, and oceanographic research in the Gulf Stream. COGLAD was patented by APL in 1974 and the patent assigned to the Government to ensure that the technology would remain available to all. One of the systems now forms the nucleus of the equipment currently being used for test purposes aboard Coast Guard vessels in the St. Marys River.

Using Loran-C for precision guidance is basically a two-step process: data measurement and data transformation. In the first step, three or more Loran transmitters and a suitable receiver provide the raw data for determining a position fix. Navigation with the raw data is awkward because the lines of position are hyperbolic curves and the units are microseconds of time difference

of arrival. Manually reducing these data to a position fix (when Loran charts are available) negates much of the true potential of Loran-C, especially in speed and accuracy. The second step consists of using some form of processor to transform the raw data mathematically into a form usable for navigation and piloting.

2. COGLAD SYSTEM DESCRIPTION

2.1 INTRODUCTION

The COGLAD system consists of an existing Coast Guard Loran Assist Device that has been modified by APL to meet the specific needs of navigating the St. Marys River. The bridge display has been completely redesigned in order to present more information to the helmsman. The Hewlett-Packard computing equipment has been expanded with the addition of an extended memory unit. The software used has been completely rewritten with expanded capabilities such as dead reckoning, continuous navigation throughout the entire river, lag compensation, and stored way points. The system presents an update to the user every 6.5 s. With the COGLAD equipment, precision navigation of the St. Marys River is possible.

2.2 HARDWARE

The hardware components of the St. Marys River COGLAD system are

1. DL-91 Loran-C receiver
2. Interface unit
3. Bridge display (new)
4. HP 9100B programmable calculator
5. HP 9101A extended memory
6. HP 9120A printer
7. HP 9125B X-Y plotter
8. HP 9102A buffer
9. Remote power supply

Figure 2 is a block diagram of the hardware configuration. The system has been installed in a 19-in. rack, approximately 3 ft high, with a desk top for the calculator stack and the X-Y plotter. Figure 3 shows the complete rack assembly, with the remote bridge display to the right. Figure 4 is a closer view of the calculator stack and bridge display. To facilitate shipment and shipboard installation, the desk top and its components can be quickly unbolted.

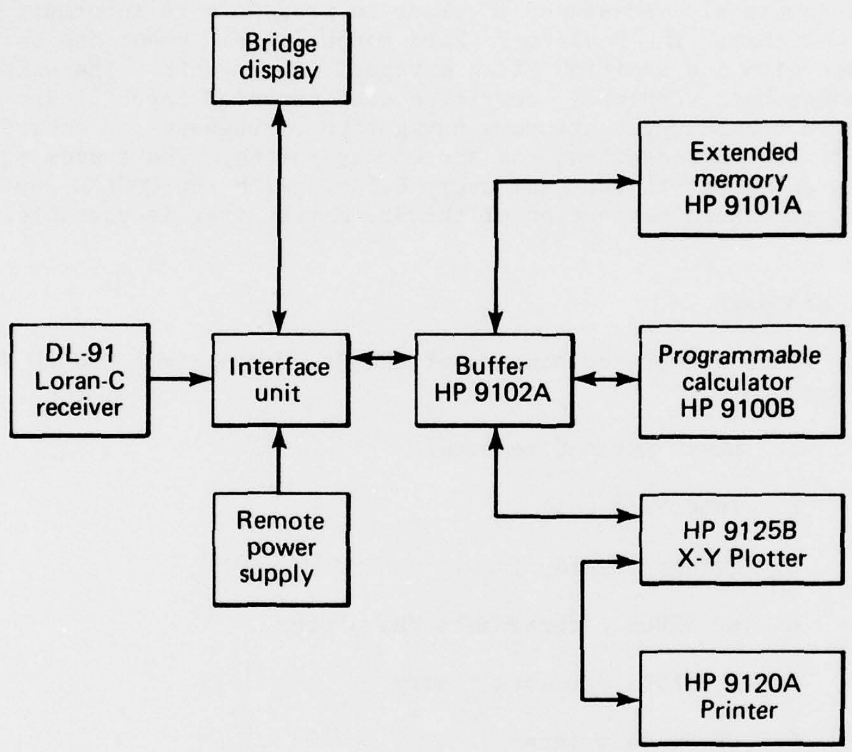

Fig. 2 Block Diagram of the St. Marys River COGLAD System

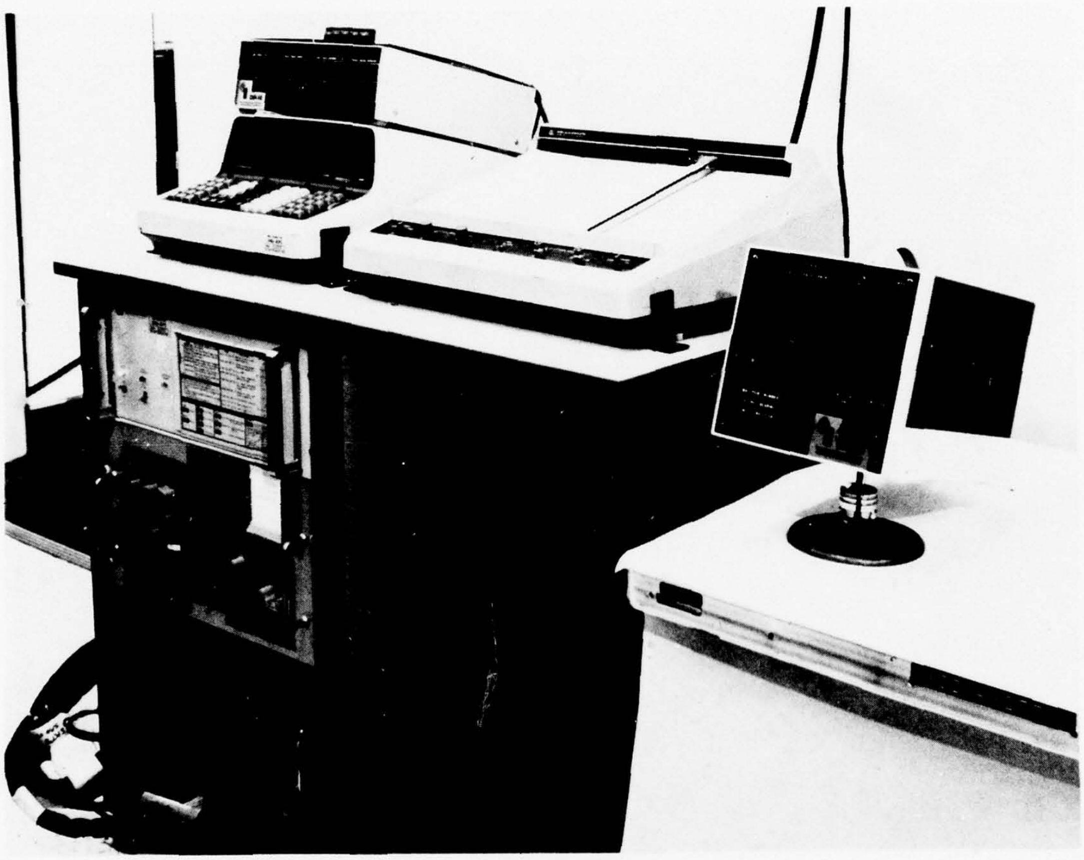

Fig. 3 St. Marys River COGLAD System, Bridge Display at Right

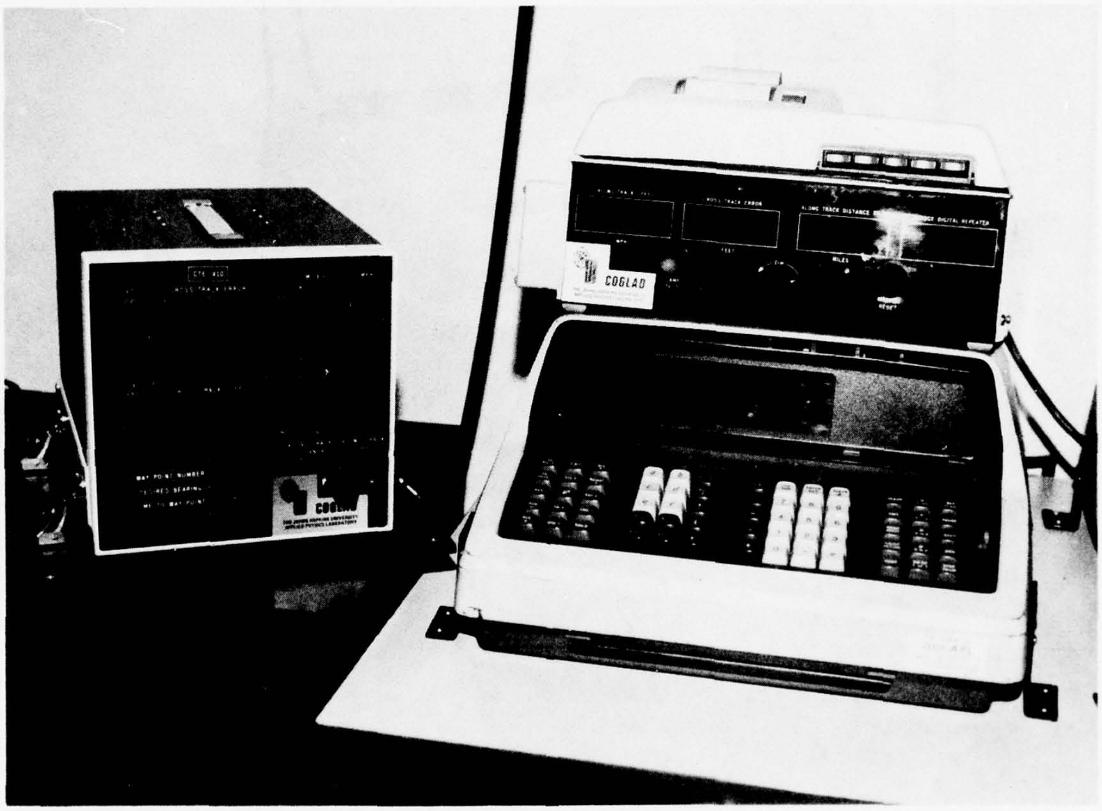

Fig. 4 COGLAD Calculator Stack and Bridge Display

Since the initial field evaluation was performed aboard Coast Guard vessels on icebreaking duty, the rack assembly is shock mounted to the deck and the bulkhead behind it. The bridge display connects to the rack assembly via a single 50-ft cable. It is mounted on an aluminum plate, approximately 10 by 12 in., with quick-disconnect latches. Total power consumption is less than 750 W of 60-Hz, single-phase AC.

2.3 SOFTWARE

COGLAD software has been completely rewritten to incorporate the way point library and to add many new features. The expansion was made possible by adding the HP 9101A extended memory, which increased the memory size by a factor of 9. About half of the extended memory is required to store sufficient way points to guide a boat from one end of the St. Marys River to the other (about 65 mi). The remainder of the memory is used for storing programs, area coefficients, constants, and variables. The major software programs, listed in detail in Appendix A, are

1. Navigation
2. Position jitter plot*
3. Statistical
4. Way point library handlers
5. Simulation*
6. Track plot*

Only the navigation program is used during actual transit of the river. All the others are special-purpose programs that are not normally stored in the extended memory. The navigation program is started by calling the navigation executive routine from the extended memory and entering the first way point number via the keyboard (see Fig. 5). After the program is started, the navigation loop is repeated continuously until the boat arrives at the way point entered in the program. The new way point loop is then executed once to enter the next number, and the program returns to the navigation loop. Whenever it is necessary to change the slave stations being tracked by the receiver or to start at a different point in the way point library, the operator halts the program and restarts as before. The printer and X-Y plotter may be enabled at the discretion of the operator.

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*Special versions of the navigation program.

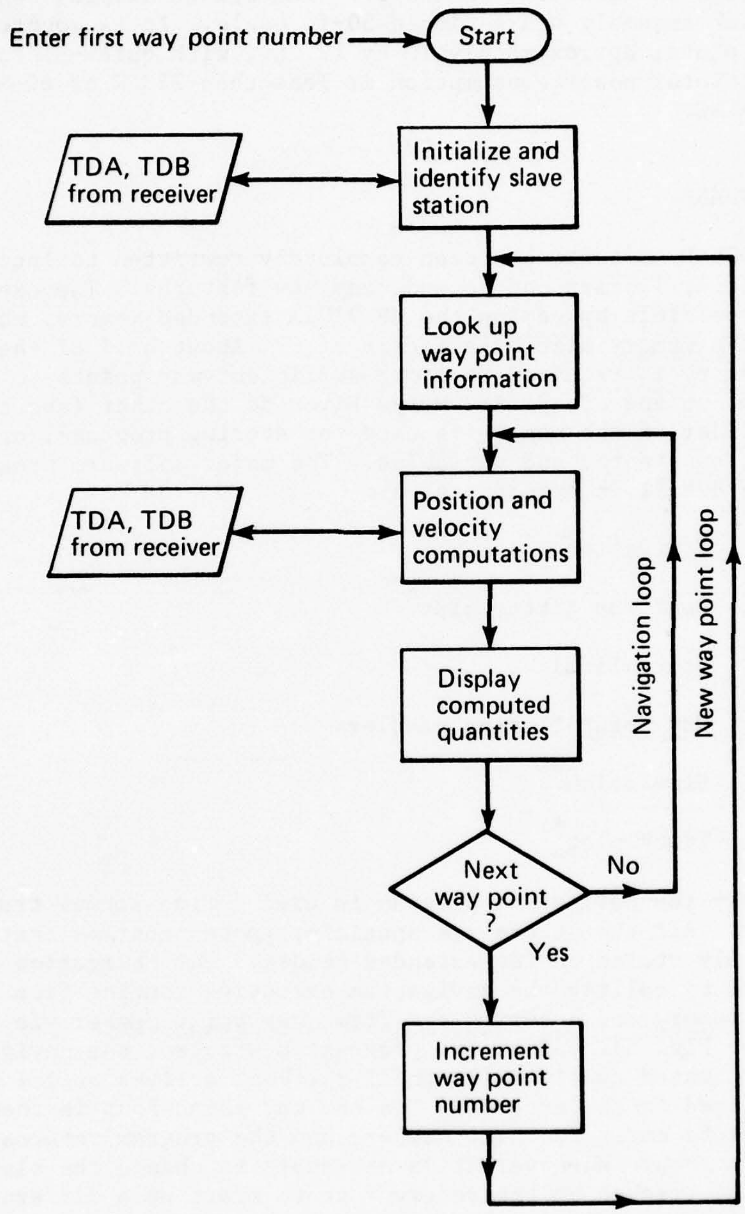

Fig. 5 Navigation Program

The position jitter plot program is used to measure total system instability, from transmitters to final processing. This is done when the boat is moored to a pier (or when it is stopped in ice); the apparent wander in Cartesian coordinates is then plotted with a greatly expanded scale.

The statistical program is used to determine the average and standard deviation of the Loran time differences (TD's) at a specific point, such as a way point. The X-Y plotter may be used to plot the drift of the two time differences being tracked by the receiver.

The way point library handlers are used to transfer way point data between magnetic storage cards and the extended memory. In normal use, a handler transfers a set of way points from magnetic cards to the extended memory prior to beginning the navigation mode. During the initial field operations, when way point libraries were being created in the extended memory, the inverse handler was used to transfer these libraries to magnetic cards.

The simulation program is used for operator training and for demonstrating the COGLAD system. It is similar to the navigation program but has a software module to simulate the motion of a boat as it proceeds from way point to way point. The program repeats continuously.

The track plot program is used to plot a high-resolution recording of the ship's track. It is a special variation of the basic navigation program.

2.4 WAY POINTS

Four routes are used by ore carriers through the St. Marys River. There is a downbound (south) summer route, a downbound winter route, an upbound summer route, and an upbound winter route. Each route can be described by a series of straight-line segments running down the center of the dredged channels. The point where the centerlines of two adjacent channels cross is defined as a way point (see Fig. 6); this represents the end of one channel and the beginning of the next. A way point is not a turning point. A turning point (i.e., where the ship starts its turn) is always before a way point and varies with the speed and maneuverability of the boat, the current, the wind, and the individual pilot. The way point is a fixed, geographically defined reference point that can be used by all vessels. Appendix B presents the locations and coordinates of the way points for the four routes.

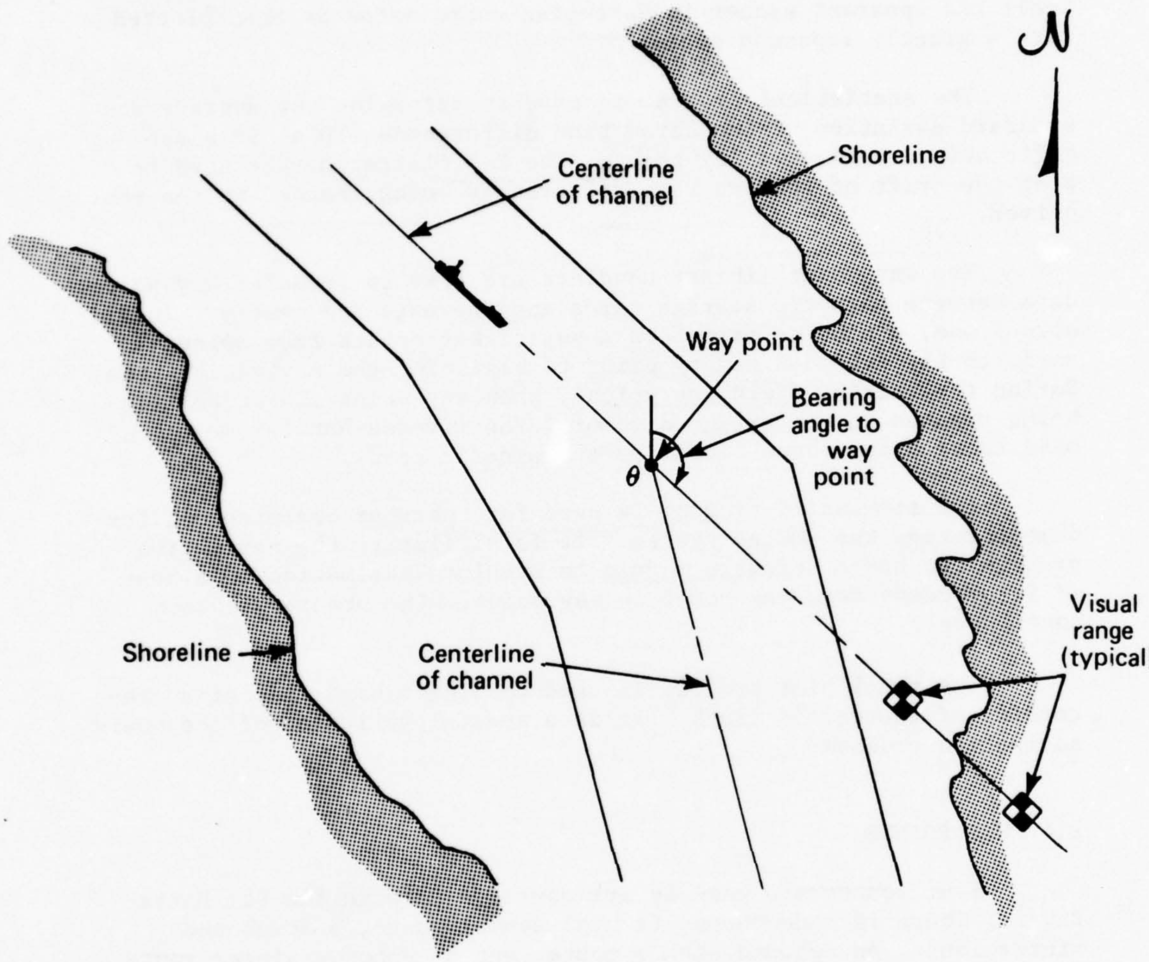

Fig. 6 Definition of a Way Point

3. HARDWARE

3.1 INTRODUCTION

Three hardware devices, unique to the COGLAD system, were designed at APL. They are the interface unit, the bridge display, and the remote power package. The system interconnections are discussed in this section, along with the new bridge display system and modifications to the interface unit for the St. Marys River COGLAD application. Other equipment (the calculator, plotter, printer, buffer, extended memory, and Loran-C receiver) were discussed in Subsection 2.2.

3.2 SYSTEM INTERCONNECTION

The interconnection of the various COGLAD system components is shown in Fig. 7. The interface unit receives time difference information from the DL-91 Loran-C receiver by counting the time lapse between master station and slave station strobe pulses. The three strobes (master and two slaves) are the only data transferred from the receiver to the COGLAD system.

The remote power supply generates DC power for the remote bridge display. The power passes through the interface unit so that only one cable is necessary to connect to the bridge display.

The COGLAD terminator plug (P221) is external to the interface unit; it provides electrical termination for nine line receivers in the interface unit.* The plug is permanently installed on J221 at the end of a short cable that extends from the real panel of the interface unit. The nine signals terminated by the plug are

NK24	Pin 1
NK20	Pin 2
NK21	Pin 3
NK22	Pin 4
NK23	Pin 5
YDSP	Pin 16
NDGO	Pin 18
NK25	Pin A
YINH	Pin R

Because YDSP is tied internally to -15 V, all nine of these signals are similarly terminated whenever the terminator plug is connected.

*These line receivers are not used in the configuration of COGLAD in use on the St. Marys River.

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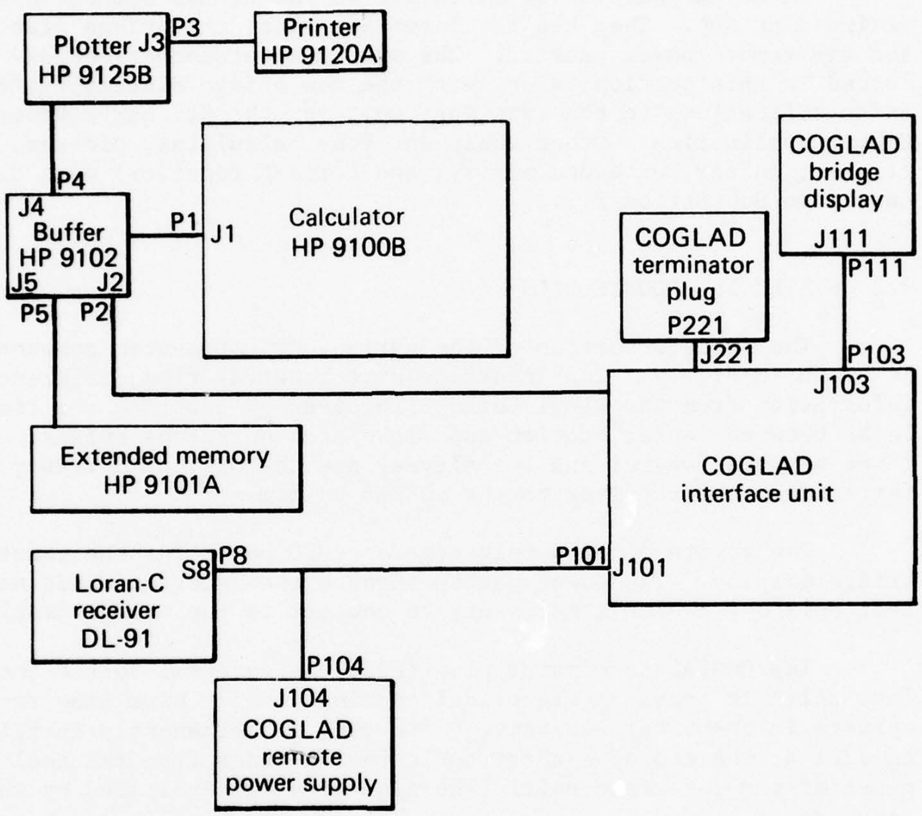

Fig. 7 St. Marys River COGLAD System Interconnections

Use of the plug improves noise immunity on the HP 9100B calculator interface lines by 40 dB.

3.3 BRIDGE DISPLAY

The bridge display provides the pilot with output information from the COGLAD navigation system. At a glance, he can see cross-track error (CTE), cross-track speed (CTS), along-track distance to go (ATD), and along-track speed (ATS).

3.3.1 Functional Description

The bridge display has four analog cursor displays under control of the COGLAD system, each consisting of 201 bars that glow (using ionized neon gas), with one bar appearing to glow brighter than the others. The position of the bright cursor bar can be controlled to ±0.5% by a digital number sent from the COGLAD system. The four analog cursor displays are CTE, CTS, ATD, and ATS. CTE is indicated on a scale from -200 to +200 ft and includes an X10 mode in which the scale is -2000 to +2000 ft. CTS can display speeds from -4 to +4 ft/s. ATD displays distance in miles from 0 to 8. ATS displays ground speed from 0 to 20 mph. The bridge display also includes a digital display and a selector switch that enable the pilot to see the way point number, the desired bearing, the time to the next way point, or ATD. There is a dimmer control to adjust the intensity of the displays to suit various ambient light conditions.

3.3.2 Mechanical Description

Figure 3 shows the St. Marys River COGLAD system, including the DL-91 Loran-C receiver, the Hewlett-Packard calculator with peripheral plotter and printer, the interface unit, and the remote bridge display. The bridge display is on the right in the figure; it can be located as far as 50 ft from the rest of the system.

Figure 8 is a close-up photograph of the bridge display itself. The figure shows the scales for the four analog cursors, the digital display window and its selector switch, and the dimmer knob. Figure 9 shows a top view of the bridge display with the cover removed, showing the 45 integrated circuits. The electronics for the bridge display have been fabricated on four circuit boards stacked horizontally inside the display box. The front panel of the display is a laminated structure consisting of two layers of Plexiglas, one layer of aluminum, and one layer of epoglass. The displays themselves are mounted in this laminated structure. One

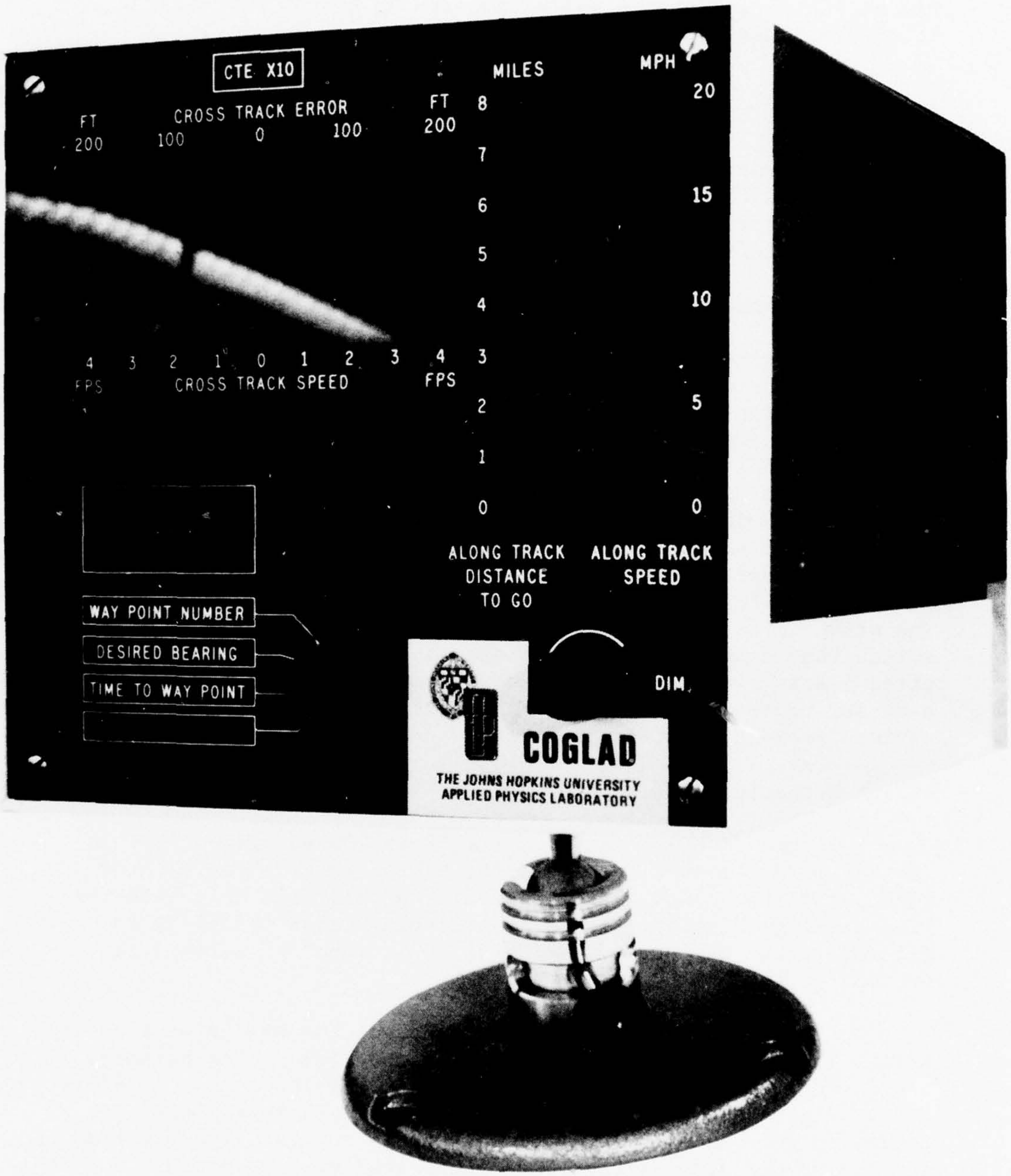

Fig. 8 Front View of St. Marys River COGLAD Bridge Display

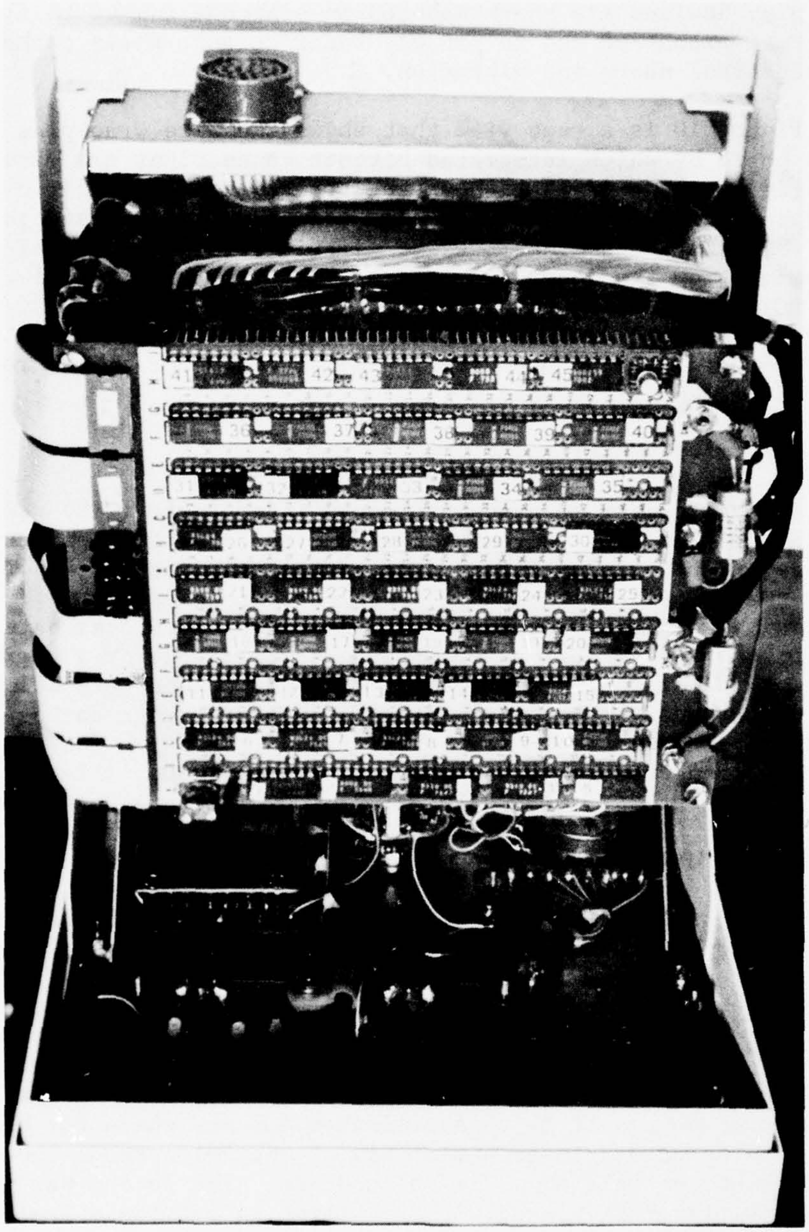

Fig. 9 Top View of Bridge Display with Cover Removed, Showing Integrated Circuit Logic

of the front Plexiglas panels is edge lighted by eight incandescent lamps, thereby illuminating the cursor scales. The analog cursor display devices are shock mounted in silicone rubber to allow for thermal expansion and to protect their ceramic/glass packages from mechanical shock and vibration.

Figure 10 is a rear view that shows the wire wrap pins on the top board by which integrated circuit connections are made; Fig. 11 is a side view that shows the top three of the four circuit board assemblies. The interface electronics are on the second board, which includes line receiver circuitry for the digital signals coming from the interface unit by way of the 50-ft cable. The DC-DC converters on the lower two boards provide 250 V DC for two pairs of cursor displays. The connector on the rear is a 32-pin MS connector that mates with a similar connector on the rear of the COGLAD interface unit.

3.3.3 Electrical Description

A small number of transistor-transistor logic (TTL) medium-scale integration (MSI) circuits are used to convert a neon dual linear bar-graph display into a dual addressable linear cursor. The bar-graph display is made by the electronic components division of Burroughs Corporation and normally displays two linear bars, whose lengths are directly proportional to a voltage or a digital number. Each bar is a neon lamp with one large anode and 201 segments, or cathodes. The first cathode, called a reset cathode, is used to initiate the neon glow at one end of the bar. The second cathode is connected to cathodes 5, 8, 11, ..., 200, called the phase one ($\phi 1$) group. Similarly, a $\phi 2$ group consists of cathodes 3, 6, 9, ..., 201, and a $\phi 3$ group consists of cathodes 4, 7, 10, ..., 199. By driving the three phases with a three-phase scanning clock, the neon glow can be made to "walk" across the entire length of the bar. At any time during the scan, the glow can be extinguished by lowering the anode voltage below the extinction voltage of the tube. When done fast enough, the scanning presents a flicker-free display.

By pausing briefly at a selected (addressable) segment during the scan, that one segment can be made to appear brighter than the others. The result is an addressable cursor, where one bright segment can be caused to appear at any of the 201 cathode locations in the bar by controlling a digital address. The second bar in the tube can be time multiplexed with the first to provide a dual addressable cursor.

Figure 12 shows the digital logic required to accomplish this. A 30-kHz oscillator drives a modulo 201 binary-coded decimal (BCD) segment counter and a reset/three-phase cathode scanner. The contents of the counter are compared with the address until a

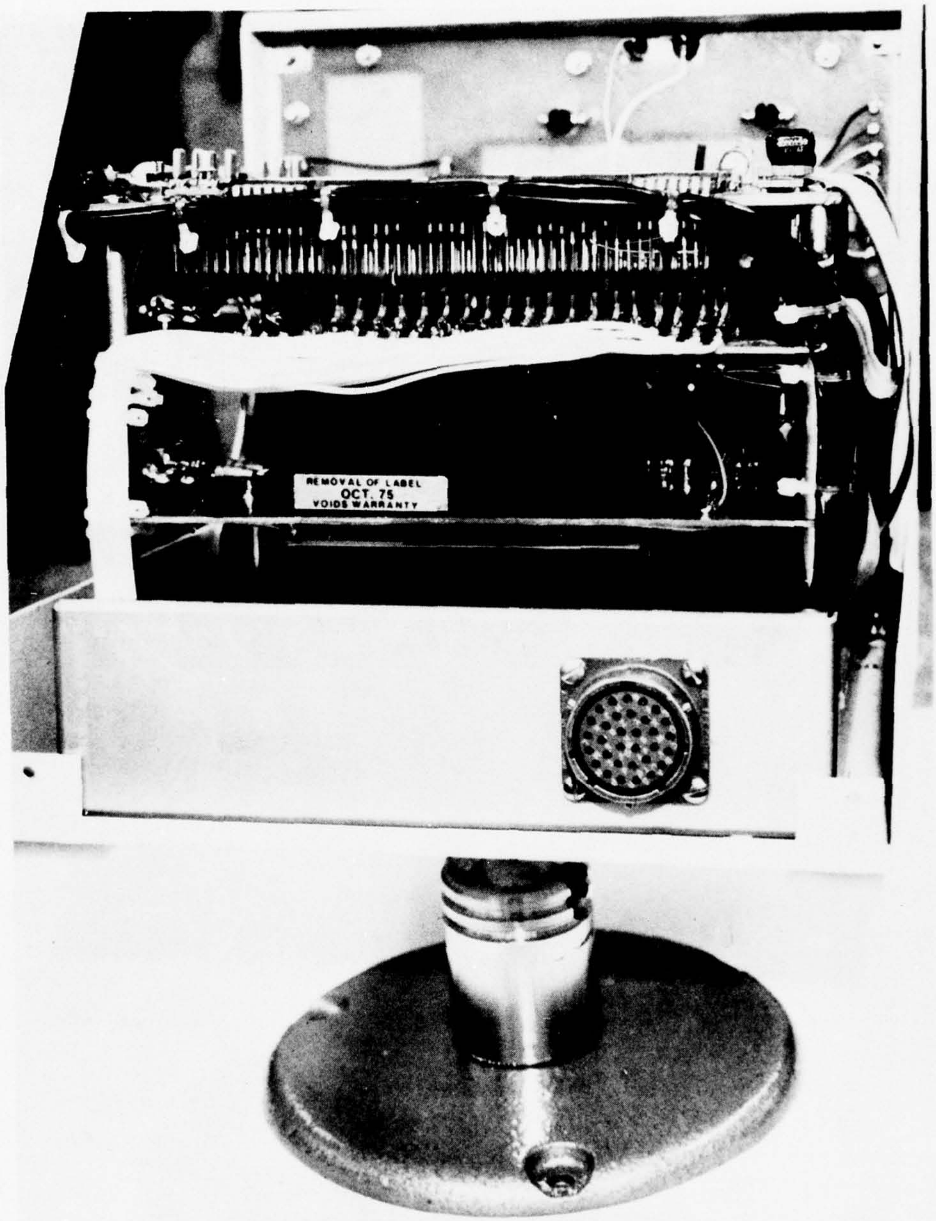

Fig. 10 Rear View of Bridge Display

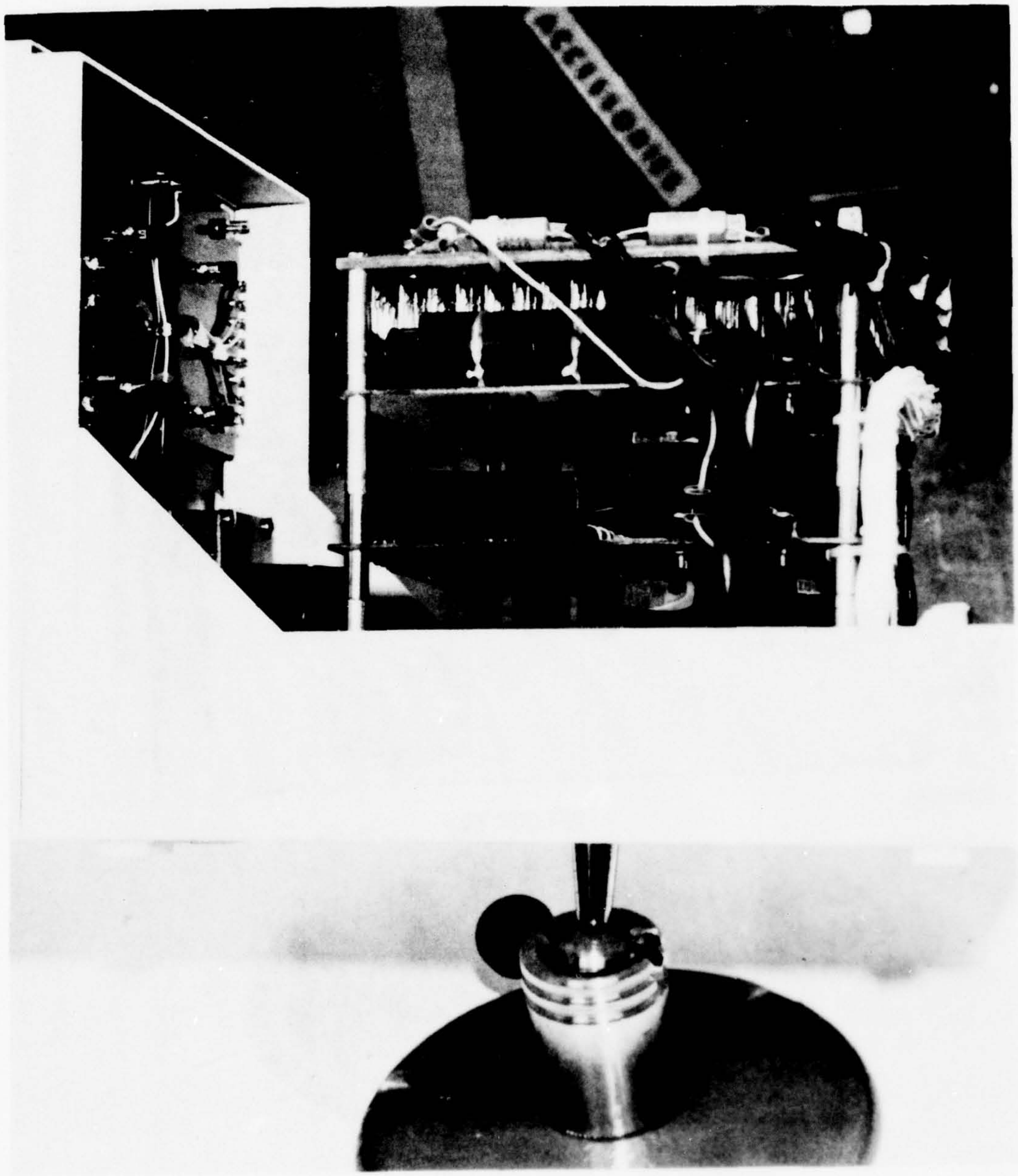

Fig. 11 Side View of Bridge Display Showing Stacked Circuit Boards

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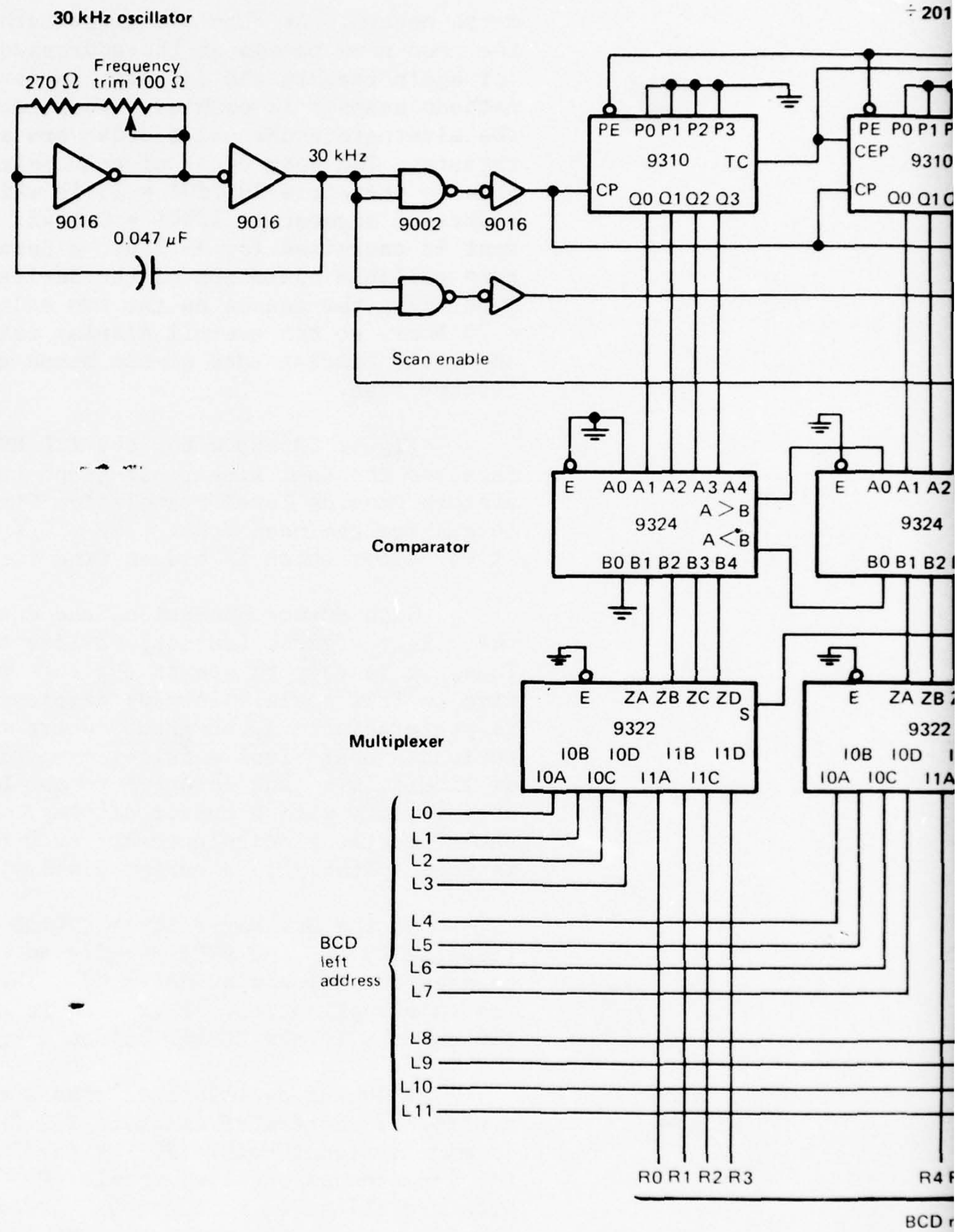

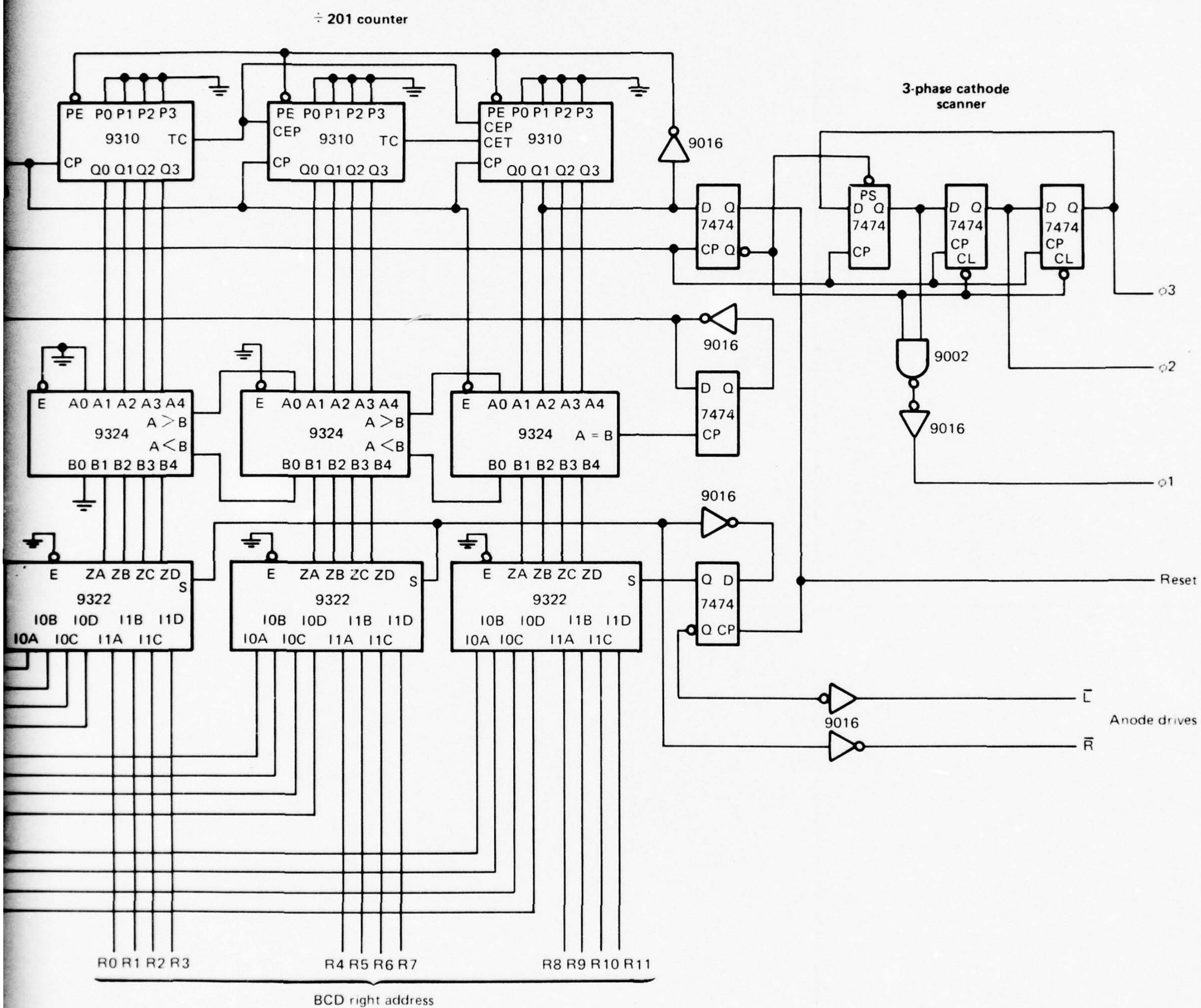

Fig. 12 Digital Logic that Converts Neon Bar Graph Display to Dual Addressable Cursor Display

match occurs. At that time, the cathode scanner is inhibited; thus the neon glow pauses at the addressed segment. When the ÷201 counter again reaches the address, as determined by the comparator, the cathode scanner is enabled. When cathode number 201 is reached, the alternate anode and address are selected, and the whole process repeats. The duty cycle of each selected (addressed) segment's glow is therefore 202/804 = 25.1% while the duty cycle of each non-addressed segment is 1/804 = 0.124%. With a 30-kHz clock, each segment is energized for 33.3 μs, a duration more than adequate to ensure reliable operation of the device. A complete scan of both bars (including the pauses on the two addressed segments) is 804 × 33.3 μs = 26.8 ms, so the overall display rate is 37.3 Hz. Since this is above the flicker rate of the human eye, the display is in effect flicker free.

Figure 13 shows how the TTL MSI circuit of Fig. 11 is interfaced to the dual linear bar-graph tube. Six high-voltage NPN transistors provide level translation from TTL levels to +70 V and +250 V levels for the neon tube. The 250 V supply also biases on the "keep-alive" glow, which is hidden from view by its opaque anode.

With cursor operation, the entire bar is always visible, and the bright segment (cursor) divides the bar into two fractions. Thus, it is easy to see at a glance the position of the cursor relative to full scale. In many display applications, a cursor display is preferable to a bar graph, where the length of the bar must be estimated apart from a full-scale reference. For example, the depth of liquid in a tank relative to the height of the tank can be seen more readily with a cursor display. Similarly, anything that indicates fractional displacement (such as a ship's rudder indicator) is more suitable to a cursor display than to a bar graph.

In the St. Marys River COGLAD system, several output values (especially CTE and CTS) require an analog display so that small changes can quickly be detected. The addressable cursor is ideal for this application. Figure 14 is a logic diagram of the ATD and ATS cursors in the COGLAD bridge display.

A 30-kHz oscillator clocks a modulo 201 decade counter consisting of integrated circuits Z3, Z4, and Z5. The decade counter is made to count modulo 201 by feeding the 200 weight output back to the synchronous parallel enable (PE) input. The parallel preset inputs are all wired to logic 0. A comparator consisting of Z6, Z7, and Z8 compares the number in the counter to the desired address, which is routed to the comparator by way of the input multiplexer Z9, Z10, and Z11. The inputs to the multiplexer are the latched addresses for the two cursor displays. When the comparator detects that the contents of the counter are equal to the selected address,

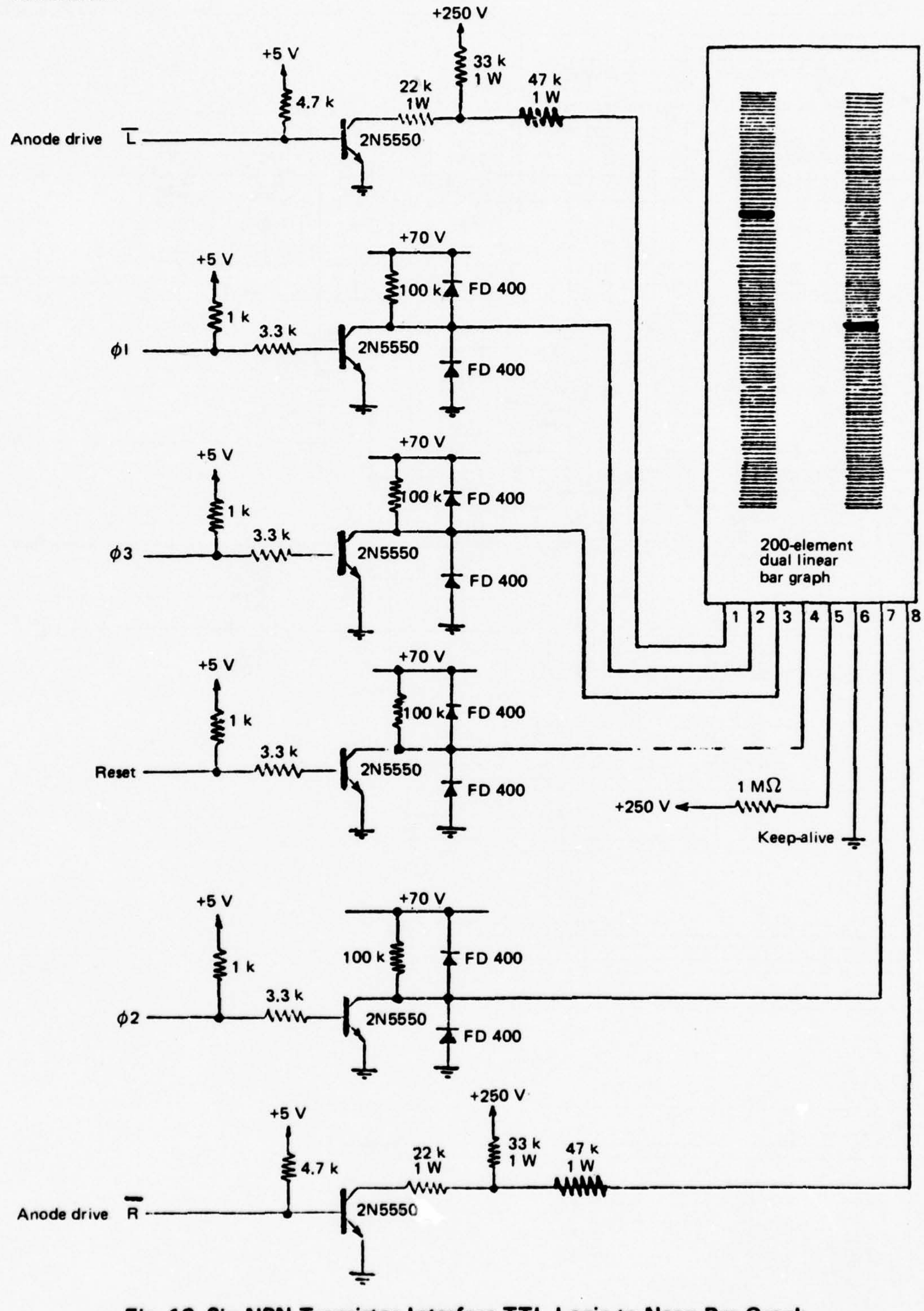

Fig. 13 Six NPN Transistor Interface TTL Logic to Neon Bar Graph Display

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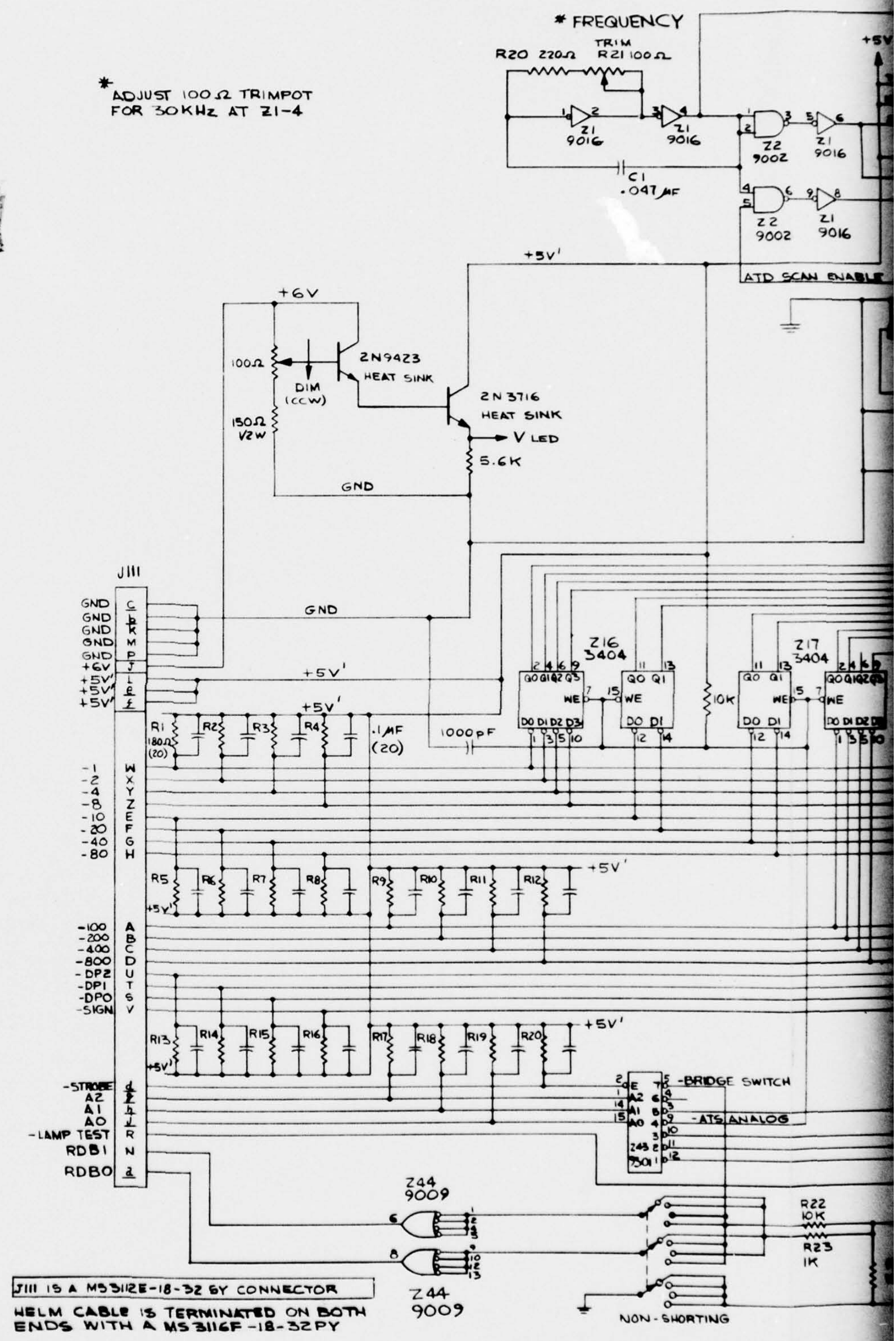

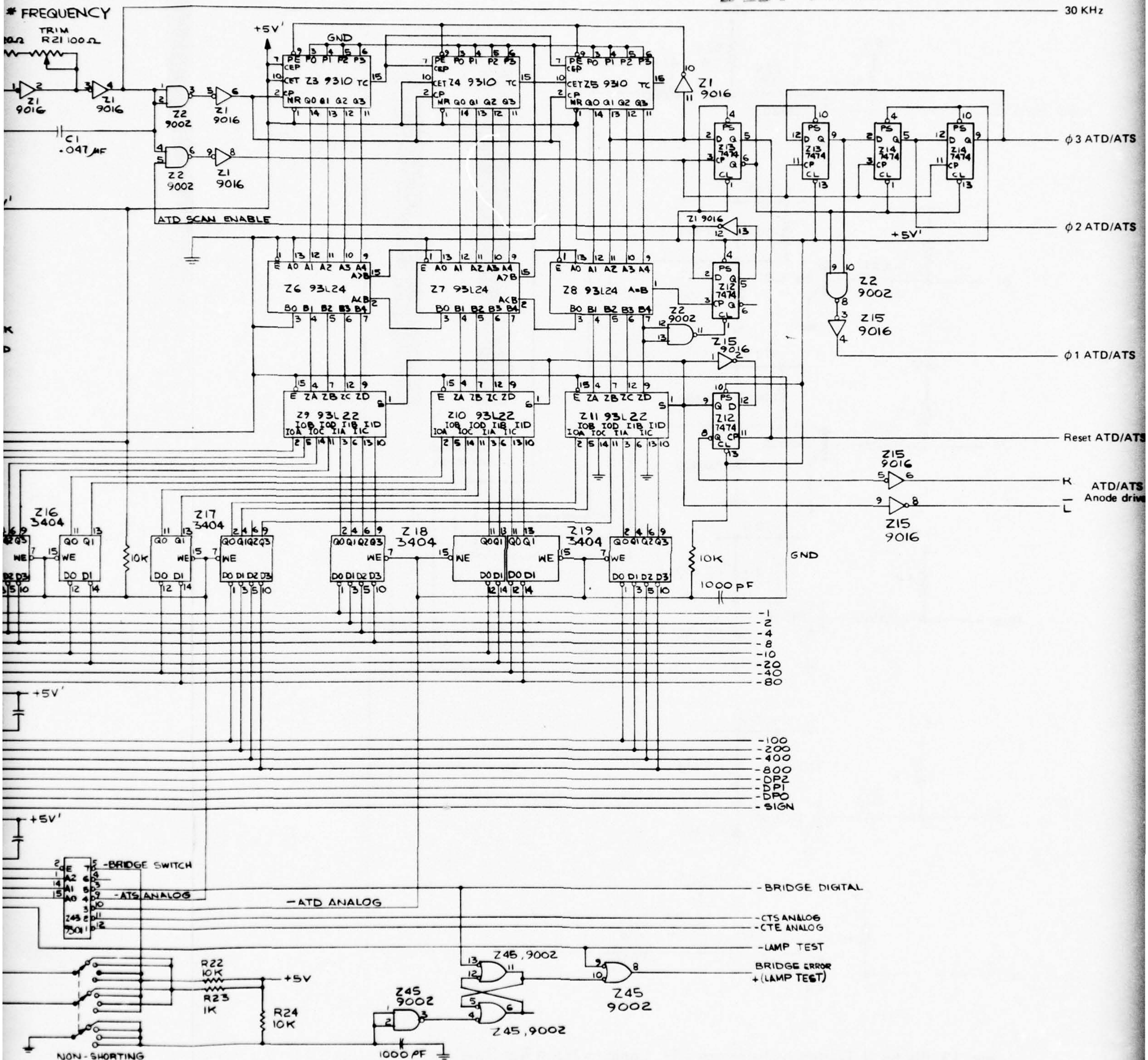

Fig. 14 St. Marys River COGLAD Bridge Display, ATD/ATS Cursors

the scan enable flip-flop is toggled. This flip-flop can inhibit the three-phase cathode scanning clock. When the scan for one display is completed, a left/right flip-flop is toggled, switching the opposite anode on. This action time multiplexes the two displays.

To strobe ATD and ATS addresses into the corresponding sets of latches, strobe signals are generated by a decoder, Z43, that decodes the data destination address, lines A0, A1, and A2. The decoder is strobed by the "strobe" signal from the interface unit. Z45 is connected as a flip-flop to detect when the operator changes the position of the bridge digital display selector switch. (One wafer of this switch has nonshorting contacts so that pins 1 and 2 of Z45 will go high briefly when the switch is between positions. This condition can then be latched and used to activate the bridge error indication on the digital display.) Lamp test is logically OR'ed with this flip-flop signal to activate the sign and decimal points. If the destination address is the bridge selector switch, the contents of the switch are encoded into two binary bits, RDB0 and RDB1. These are buffered and transmitted back to the COGLAD interface unit.

A Darlington emitter follower generates a variable voltage for the front panel displays, V_{LED}. The input to the emitter follower is the output from the wiper arm of the dimmer potentiometer.

Figure 15 shows the logic for the CTE and CTS cursors in the bridge display. These cursors are identical to the ATD and ATS cursors in all respects. Figure 15 also shows the latches and drivers for the bridge digital display, which receives its data, address, and strobe from the same lines as the analog displays. Figures 16 and 17 show how the digital logic circuits of Figs. 14 and 15 are interfaced to the high-voltage neon bar-graph displays.

The bridge display is powered by the +5 V power supply in the remote power supply unit. Power requirements are +5 V at 6.2 A, worst case.

3.4 MODIFICATIONS TO INTERFACE UNIT

3.4.1 Bridge Display Interface Modifications

Certain hardware modifications had to be made to the COGLAD interface unit to drive the bridge display. The original interface is documented in "COGLAD: A Coast Guard Loran-C Assist Device."* Twenty-eight integrated circuits were removed from the

*R. C. Moore, C. R. Edwards, R. K. Burek, and G. D. Wagner, "COGLAD: A Coast Guard Loran-C Assist Device," APL/JHU CP 026, March 1973.

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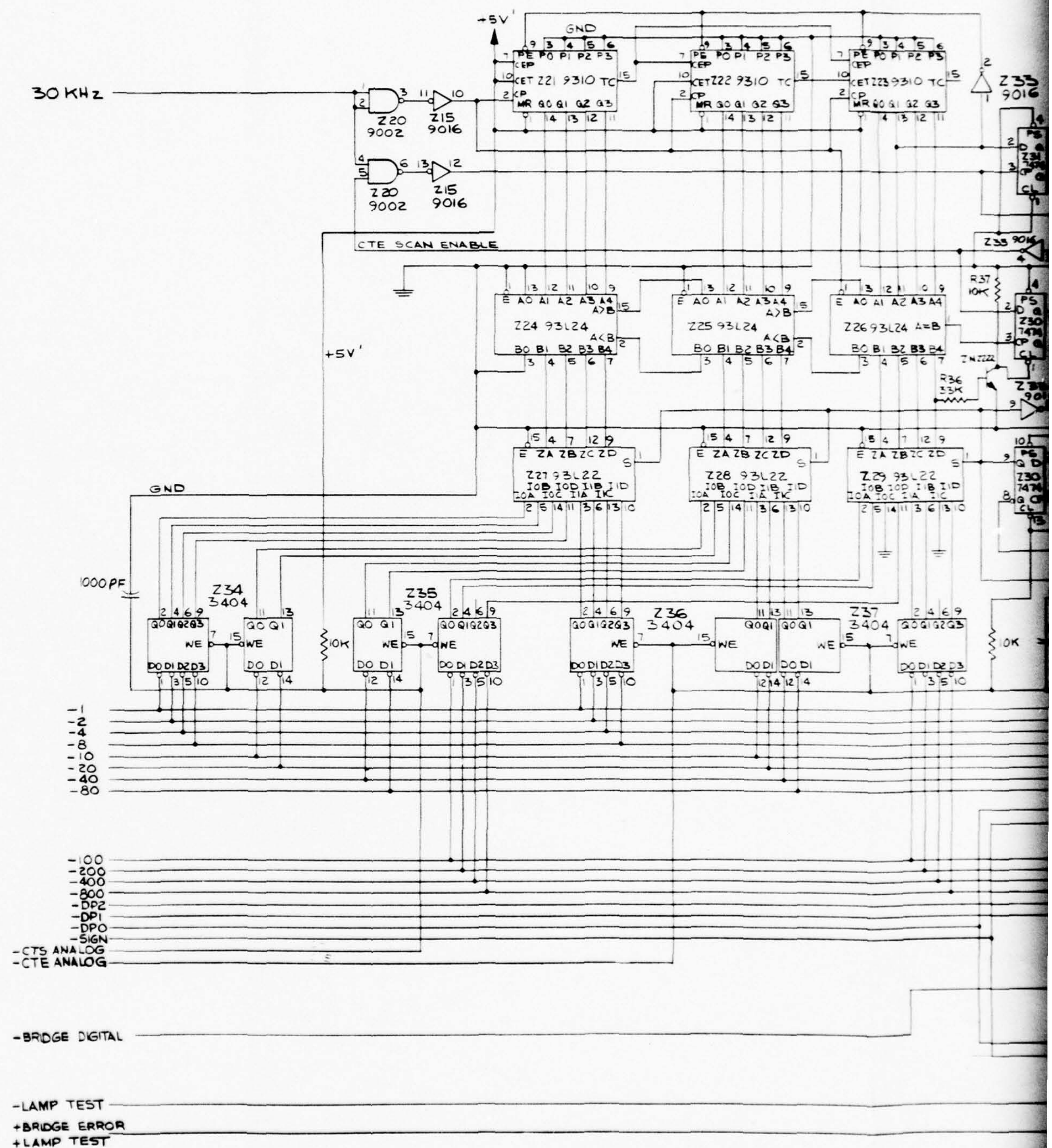

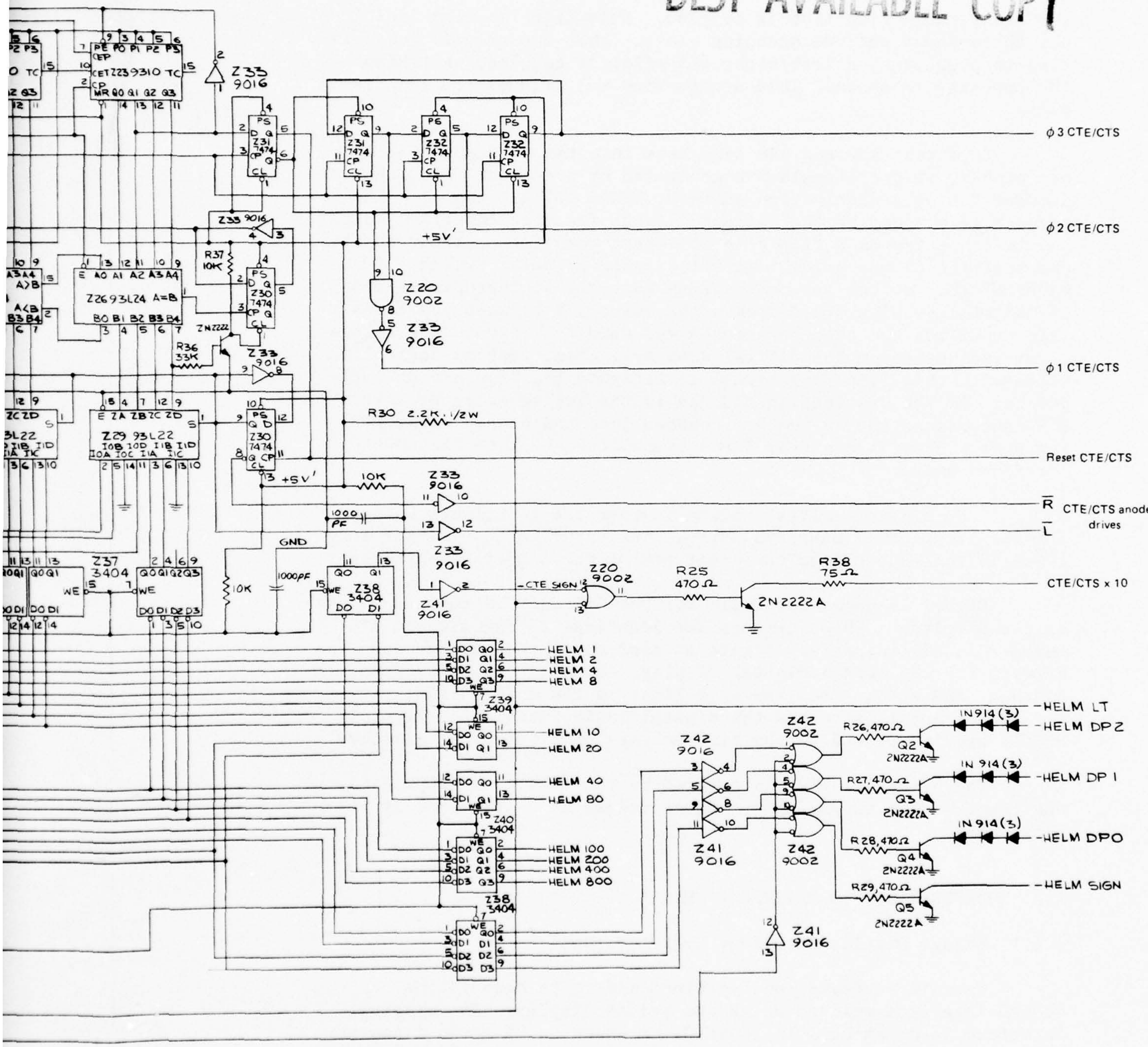

Fig. 15 St. Marys River COGLAD Bridge Display, CTE/CTS Cursors

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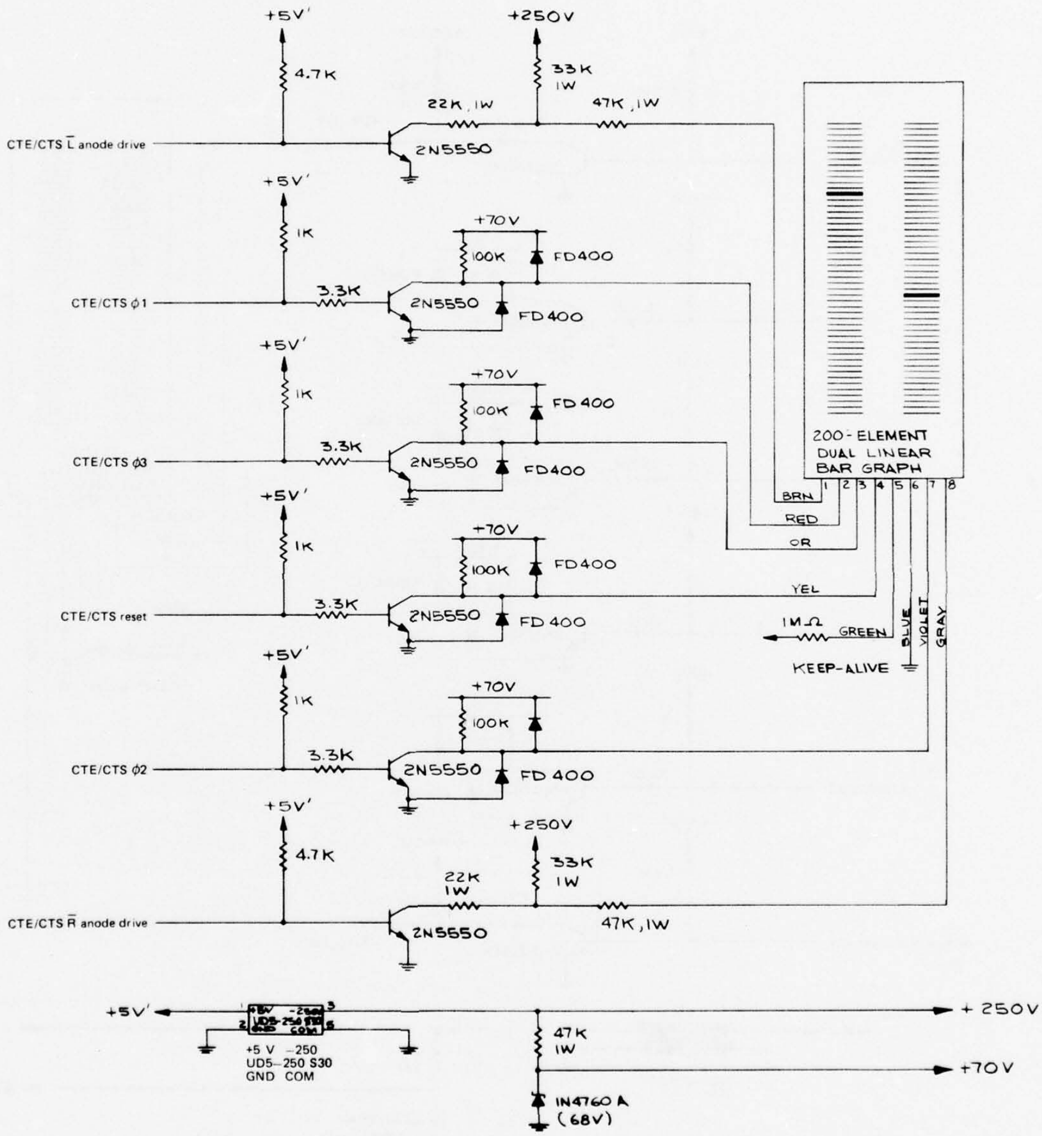

Fig. 16 St. Marys River COGLAD Bridge Display, CTE/CTS Bar Graph Interface

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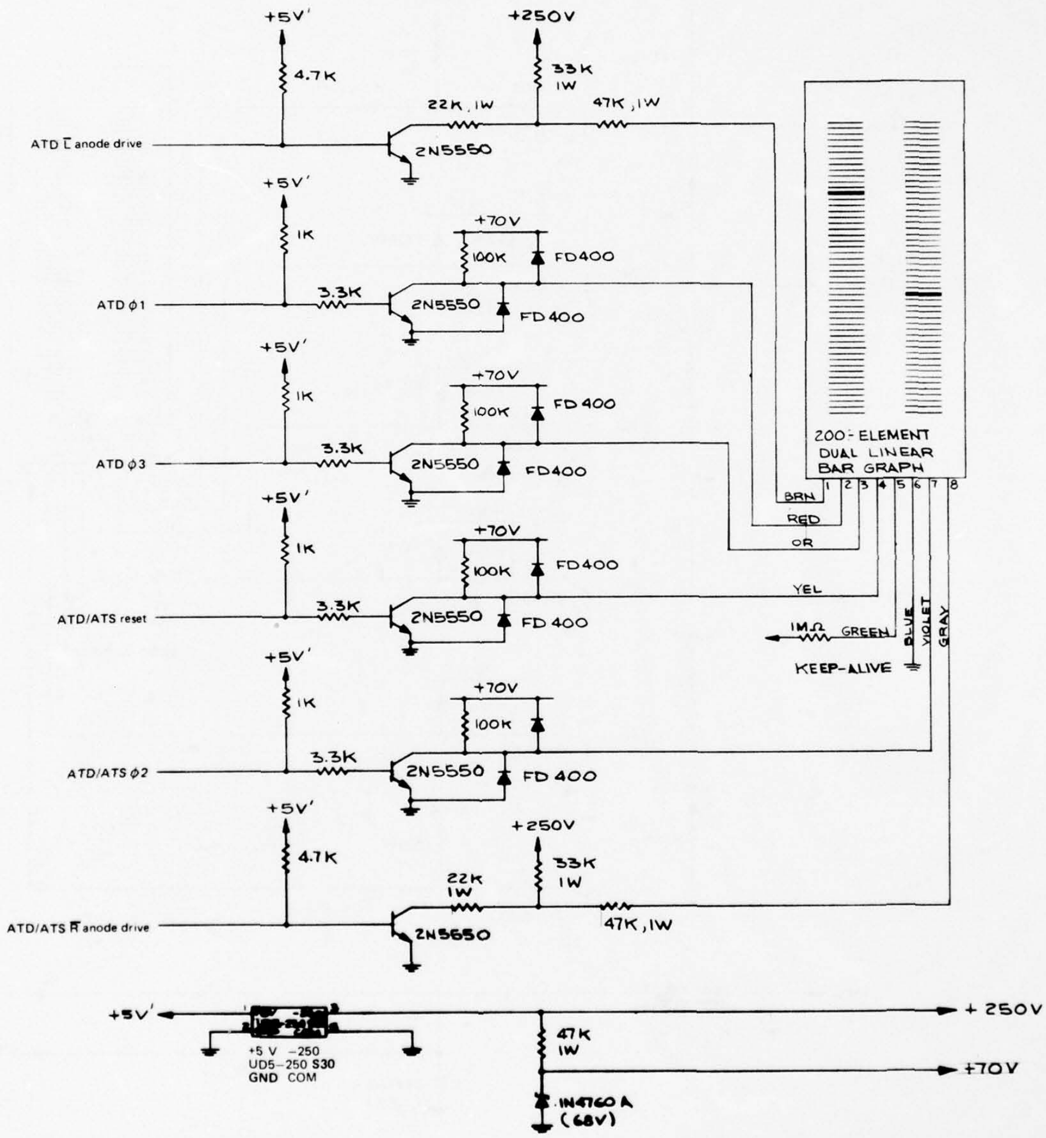

Fig. 17 St. Marys River COGLAD Bridge Display, ATD/ATS Bar Graph Interface

display logic section, namely Z101-104, Z106-109, Z111-114, Z116-119, and Z121-132. The following integrated circuits were added:

Z101 (9007)	Z103 (9318)	Z106 (9009)
Z107 (9009)	Z109 (9009)	Z111 (9009)
Z112 (9009)	Z113 (9009)	Z114 (9009)
Z116 (9009)	Z117 (9009)	Z118 (9009)

Figure 18 shows how eight 9009 line drivers provide the bridge display with data derived from a set of latches in the display logic section of COGLAD. Figure 19 shows the logic required to transfer data addresses to the bridge display and to steer the data to the appropriate latches in the bridge display. Addresses are decoded from the HP 9100B format codes in the interface logic section of COGLAD and then reencoded according to the tabulation in Fig. 18. A 2-ms strobe pulse alerts the bridge display when new data and addresses are available.

3.4.2 Hardware Format Codes

Eleven HP 9100B format (FMT) codes are used by the St. Marys River COGLAD system, consisting of three input and eight output formats. They are listed with their functions in Table 1 and discussed in detail in the following subsections.

Table 1

St. Marys River COGLAD Format Codes

Format	Function
Input	
ACC-	Filtered TDA, TDB input
HYPER▼	Filtered $\dot{\mathrm{TDA}}$, $\dot{\mathrm{TDB}}$ input
COS X	Time, bridge switch inputs
Output	
3	Reset microprocessor
7	CTE digital
a	ATS digital and analog
d	ATD analog
X → ( )	ATD digital
CLEAR X	CTE analog and CTE X10 lamp
CONTINUE	CTS analog
IF X > Y	Bridge digital displays

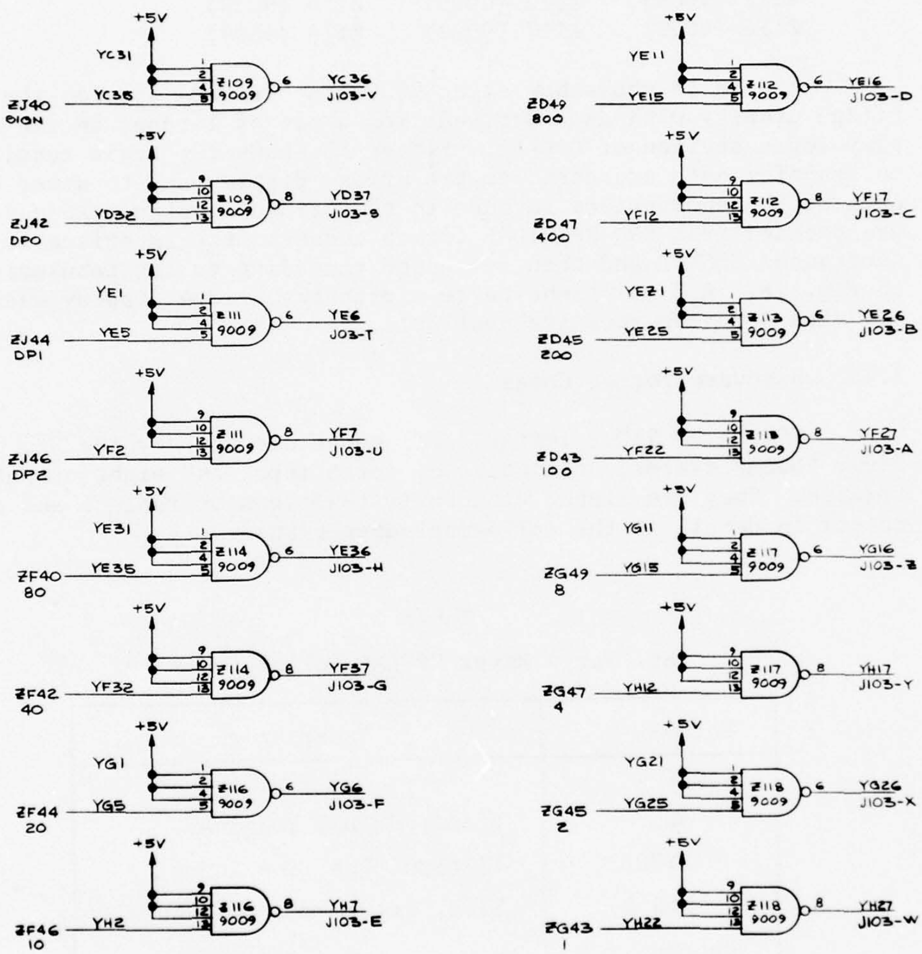

Fig. 18 St. Marys River COGLAD Bridge Display, Line Drivers

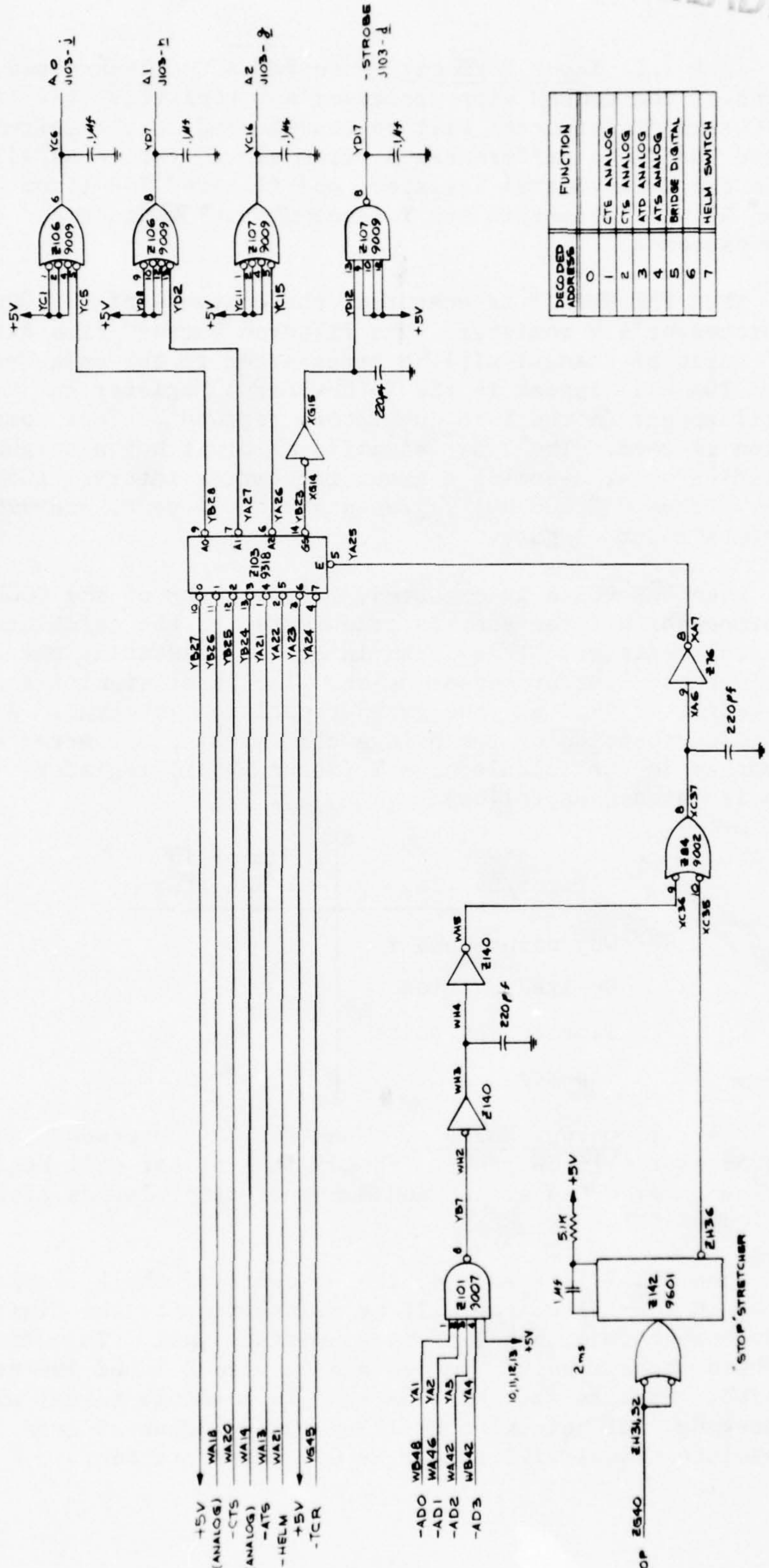

Fig. 19 Address Bus Generator in Interface Unit

3.4.2.1 Input Formats. When FMT ACC- is executed, the contents of the COGLAD microprocessor's F registers (the filtered Loran-C time differences) will be transferred to the calculator. Filtered TDA (time differences A, from slave station A) will appear in the X (keyboard) register, and filtered TDB (from slave station B) will appear in the Y (accumulator) registers. Units are nanoseconds.

When FMT HYPER▼ is executed, the contents of the COGLAD microprocessor's V registers (the filtered Loran-C time differences' rates of change) will be transferred to the calculator. Filterd $T\dot{D}A$ will appear in the X (keyboard) register and filtered $T\dot{D}B$ will appear in the Y (accumulator) register. Tens complement notation is used. The least significant digit has a weight of 1.014198783 ps/s, assuming a group repetition interval (GRI) of 49.3 ms. Thus 000 000 001 represents about 1 ps/s, and 999 999 999 represents about -1 ps/s.

When FMT COS X is executed, the contents of the COGLAD microprocessor's T register is transferred to the calculator's X (keyboard) register. This is an integer representing the elapsed time since the last processor reset. The least significant digit has a weight of 49.3 ms, the group repetition interval. Also, the encoded position of the bridge digital display sector switch will appear in the calculator's Y (accumulator) register. This switch is encoded as follows:

Switch Setting	Number in Y Register
Way point number	0
Desired bearing	1
Time to way point	2
(spare)	3

3.4.2.2 Output Formats. When FMT 3 is executed, the COGLAD microprocessor will be reset. The digital filter will begin, at the present Loran-C position and zero velocity, 740 ms after the execution of FMT 3.

When FMT 7 is executed, the contents of the X (keyboard) register in the calculator will be transferred to the digital CTE display on the front panel of the interface unit. In addition to 0, numbers whose absolute values are between 0.1 and 999 can be displayed. Numbers greater than 999 (in absolute value) will cause all three decimal points to be illuminated. Numbers less than 0.1 (in absolute value) will appear as 0. Units are feet.

When FMT a is executed, the contents of the X (keyboard) register in the calculator will be transferred to the digital ATS register and the "analog" ATS cursor. The number in the X register must be in the range

$$400 \leq ATS \leq 600$$

for the cursor display to operate properly. The number 400 will display 0.0 mph and the number 600 will display 20.0 mph. The digital ATS display is on the front panel of the interface unit, and the analog ATS cursor is on the remote helm display. The sign of the X register is ignored, so numbers in the range

$$-600 \leq ATS \leq -400$$

are also effective. In that case, -400 displays 0.0 mph and -600 displays 20.0 mph.

When FMT d is executed, the contents of the X (keyboard) register in the calculator will be transferred to the analog ATD cursor on the remote helm display. Again, the sign is ignored, so that numbers in the X register must be in the range

$$\pm 400 \leq |\text{ATD analog}| \leq \pm 600$$

for the cursor display to operate properly. The number ±400 will display 0 mile and the number ±600 will display 8 miles.

When FMT X → ( ) is executed, the contents of the X (keyboard) register in the calculator will be transferred to the digital ATD display register on the front panel of the COGLAD interface unit. In addition to 0, numbers whose absolute values are between 0.001 and 999 can be displayed. Values greater than 999 will cause all three decimal points to be displayed. Values less than 0.001 will be displayed as 0. Negative numbers are allowed.

When FMT CLEAR X is executed, the contents of the X (keyboard) register in the calculator will be transferred to the analog CTE cursor on the remote helm display. Numbers in the X register must be in the range

$$\pm 400 \leq |\text{CTE analog}| \leq \pm 600$$

for the cursor to operate properly. Negative numbers in this range will cause the CTE X10 lamp to light, so while +400 corresponds to -200 ft and +600 corresponds to +200 ft, -400 corresponds to -2000 ft and -600 corresponds to +2000 ft. Plus or minus 500 corresponds to 0 ft.

When FMT CONTINUE is executed, the contents of the X (keyboard) register in the calculator will be transferred to the analog CTS cursor on the remote helm display. The sign is ignored, so numbers in the range

$$\pm 400 \leq |\text{CTS analog}| \leq \pm 600$$

correspond to cross-track speeds in the range

$$-4 \text{ ft/s} \leq \text{CTS} \leq +4 \text{ ft/s}$$

with ±500 corresponding to 0 ft/s.

When FMT IF X > Y is executed, the contents of the X (keyboard) register in the calculator will be transferred to the digital light-emitting diode (LED) display on the remote bridge display and to the fourth digital display on the front panel of the COGLAD interface unit (these two displays always display identical data). In addition to 0, numbers in the range

$$0.001 \leq |\text{bridge digital}| \leq 999$$

can be displayed. Units for this display are a function of the bridge digital display selector switch. With the switch in position "0," units are integers (way point numbers) between 1.00 and 999. In switch position "1," units are degrees between 0.001° and 359°. In switch position "2," units are min, between 0.001 and 999 min. Negative numbers can be displayed.

4. OPERATING PROCEDURE

4.1 INTRODUCTION

COGLAD was developed to enhance shipboard use of Loran-C. The system uses the DL-91 Loran-C receiver, the HP 9100B programmable calculator, and an interface unit developed at APL. COGLAD provides the navigator with a heading angle and position, velocity, and a real-time plot of the ship's position relative to the centerline of the channel. Steering information is displayed simultaneously to the helmsman.

Using the COGLAD system, a ship can navigate the entire St. Marys River with a minimum of operator intervention. Before using the COGLAD system for navigation, the operator must enter the intended route's way points in the extended memory, and the DL-91 receiver must be locked to the preferred pair of slave stations. At this point, the operator performs a minimum number of instructions that start the navigation mode. The only item in the system that requires constant attention is the plotter if it is used (if the plotter or printer is not used, it must be connected and powered but have its function disabled). Approximately midway in the ship's transit of the river, the operator will be required to change the slave stations locked on the DL-91 as the preferred pair changes at that point. When the ship has completed the journey, the COGLAD system is powered down. In summary, an operator is required to power up and initialize the system prior to using COGLAD, to change slave stations midway through the trip, and to power down at the completion of the trip.

By convention, distances in the Great Lakes are given in terms of statute miles. For this reason, all distances displayed are in terms of statute miles or feet.

4.2 OPERATIONAL DESCRIPTION

4.2.1 Interface Unit

Figure 20 is a block diagram of the four major sections of the interface unit: the Loran-C receiver interface, the processor, the calculator interface, and the display logic.

The receiver interface section accepts tracking strobes (timing pulses) from the receiver. A 50-MHz oscillator in the interface unit measures the time delay from the master station tracking strobe to the slave station A tracking strobe. The measurement

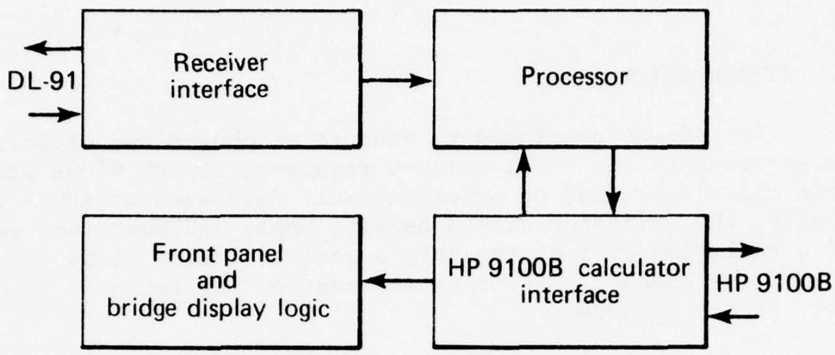

Fig. 20 Block Diagram of COGLAD Interface Unit

is time difference A (TDA). On the next set of tracking strobes, the time delay from the master station to slave station B is measured (TDB). The exact rate at which sets of tracking strobes become available depends on the pulse recurrence rate (prr) of the Loran chain being used; for the mini-Loran chain it is slightly less than 0.05 s. Thus, the interface unit determines about 10 new position fixes (TDA and TDB) per second.

The processor section smooths (i.e., maintains a running average on) the TD's and stores them until the calculator calls for position data. The processor is programmable and has two hardwired programs on plug-in read only memory (ROM) cards. Each program is defined by the pattern of diodes soldered on a plug-in card in the interface unit. One card contains the filter or "flywheel" program and controls the amount of smoothing. The other card contains the initialization program that clears and resets the storage registers in the processor. Pressing the MASTER RESET switch causes the initialization program to be executed for about 0.8 s. The processor then automatically switches to the operating instructions.

The calculator interface section accepts and decodes requests from the calculator for data transfers. Smoothed TD's for computing position and velocity are transferred from the interface unit to the calculator, and data to be displayed are transferred from the calculator to the interface unit.

The display logic stores the data to be displayed and provides the appropriate logic signals to control the digital display registers and the analog displays. Table 2 defines the information, units, and range of the digital display registers.

Table 2

Display Registers on Front Panel of Interface Unit

Information	Largest Number	Smallest Number	Remarks
Along-track speed (mph)	+20	+0.1	Display truncated to tenths of mph
Cross-track error (ft)	±999	±0.001	Display not truncated
Along-track distance to go (mi)	±999	±0.001	Display not truncated
Bridge digital repeater	--	--	Repeats whatever is requested on bridge display

4.2.2 Bridge Display

The bridge display consists of one selectable digital and four analog displays. The digital display will show one of the following four quantities: way point number, desired bearing, time to way point, and along-track distance to go. The desired quantity is selected by the operator. The analog displays indicate the distance on the centerline of the channel to the way point (i.e., ATD), the distance from the centerline of the channel (i.e., CTE), the speed along the centerline of the channel (i.e., ATS), and the speed at right angles to the centerline (i.e., CTS). Table 3 defines the information, units, and range of the analog displays.

Table 3

Analog Displays on Bridge Display

Information	Largest Number	Remarks
ATD	8 mi	
CTE	±200 ft	Has X10 capability
ATS	20 mph	
CTS	±4 ft/s	

The bridge display receives data from the interface unit. The displays are updated once each machine cycle, or 6.5 s.

4.3 CONTROL FUNCTIONS

4.3.1 Interface Unit

DIM: Rotating the DIM control clockwise will increase the brilliance of the digital display registers.

LAMP TEST: Pressing the LAMP TEST switch causes all digital display registers, including the digital readout on the remote bridge display, to display all 8's, decimal points, negative signs, and left/right indicator lights. (Note: LAMP TEST does not reset or modify numbers in the processor.)

MASTER RESET: Pressing the MASTER RESET switch interrupts the processor, loads unfiltered TD's from the receiver directly into the interface processor, and sets the velocity registers and the master cycle counter to 0. LAMP TEST is energized for the duration of the master reset cycle. All digital displays indicate 0 after the completion of a master reset cycle.

4.3.2 Bridge Display

DIM: Rotating the DIM control clockwise will increase the brilliance of analog display, panel lighting, and digital display.

SELECTOR SWITCH: Rotating the SELECTOR SWITCH control will select one of the four quantities: way point number, desired bearing, time to way point, or ATD.

4.4 COGLAD NAVIGATION MODE

The navigation mode consists of an executive routine, numerous subroutines, and several reference tables. The heart of the navigation program (Table 4) is a coordinate conversion algorithm from Loran hyperbolic coordinates to Cartesian coordinates. The algorithm is the same as that currently used in C-LAD.* The remainder of the navigation program is primarily scaling, checking data, and sending data to displays. The reference tables consist of two kinds. Table 5 shows values and formats of precomputed and predetermined numbers for the St. Marys River minichain and Table 6

*L. M. Marshall, Jr., and C. R. Edwards, "C-LAD — A Low-Cost Loran-C Assist Device; Volume II — Software," APL/JHU CPO 34B, June 1974.

Table 4

Navigation Program

Program Number	Location in Extended Memory	Acronym	Title	Function
00	90-99	EXECUTIVE	Executive	Main controller calls all subprograms and makes major decisions.
11	0-7	IASSID	Initialize, Store Way Point Number, and Identify Secondary Station	Initializes program registers, stores way point number, and identifies secondary stations.
21	8-17		Computing of A,B,C,D,E', and F'	Computes and stores constants for conversion equations which are dependent on secondary stations.
22	18-23		Computing of A',B',C',D',E', and F'	
31	24-28	WPLUP	Way Point Look-Up Program	Uses way point number to retrieve information from way point library.
41	29-35		Computing of μ_A,μ_B,E, and F	Given a pair of TD's, computes the X and Y coordinates.
42	36-44		Computing of β,δ,α, and γ	
43	45-53		Computing of ξ,ζ',η,θ_m, X, and Y	
51	54-58	XYDR	Dead Reckon X and Y Coordinate	Using previous position and velocity information, computes a new position by dead reckoning.
61	59-63	TSTPP	Test Present Position Coordinates from TD's against Dead Reckoning	Checks present position to determine validity of TD's.
62	64-71	PPDATA	Present Position Data Computation	Performed when present position from TD's is used, computes velocity.
71	72-77	ATCT	Along-Track and Cross-Track Data	Controlling program for computing and displaying ATD, CTE, ATS, and CTS.
72	78-79	AROT	Angular Rotation	Performs angular rotation on data to reference them with respect to center of channel.
73	80-86	DATCT	Displays ATD and CTE	Scales and displays ATD and CTE.
74	87-89	DATCTS	Displays ATS and CTS	Scales and displays ATS and CTS.
81	117	DDHD	Decode Digital Helm Display	Decodes switch on helm display and displays appropriate quantity.

Table 5

Table of Contents

Address	Variable	Contents	Units
100	X_m	36.288682	Thousands of yards
101	Y_m	-7.178112	Thousands of yards
102	X_x	-5.303108	Thousands of yards
103	Y_x	-49.05059	Thousands of yards
104	AEDX	11221651.9	Nanoseconds
105	X_y	57.32658	Thousands of yards
106	Y_y	-62.4283	Thousands of yards
107	AEDY	22220332.4	Nanoseconds
108	X_z	-15.2271	Thousands of yards
109	Y_z	17.4697	Thousands of yards
110	AEDZ	33227934.	Nanoseconds
111	V_p	0.0003278589	Thousands of yards/ nanoseconds
112	K_1 Dead reckoning	6.5	Seconds
113	K_2 $\|\Delta\|$ window	1000	Thousands of yards
114	K_6 LAG	15	Seconds
115	K_4 Time conversion	0.0493	Seconds/GRI
116	K_5 Velocity filter	0.3	None

Table 6

Way Point Library Organization

Address	Variable	Contents	Units
118+(WP#-1)	TDX	11 XXX XXX.	Nanoseconds
119+(WP#-1)	TDY	22 XXX XXX.	Nanoseconds
120+(WP#-1)	TDZ	33 XXX XXX.	Nanoseconds
121+(WP#-1)	θ_D	XXX.XXX	Degrees

illustrates the format of measured and precomputed numbers for a given route on the St. Marys River (see Appendix B for the specific values).

The operator starts the navigation program by calling the executive routine from the extended memory to the calculator, entering the first way point number, and pressing the CONT key. The program will then run automatically to the end of the route or until stopped. (Note: the operator is required to change the graph paper after every three way points if the plotter is used.)

The navigation program begins by calling several initializing subroutines before entering the navigation loop (see Fig. 5). The display registers are cleared to 0, and the program determines which two of the three slave stations are being used by the receiver by examining a set of TD's from it. Having determined the slave stations, the program computes six constants, A', B', C', D', E', and F', using the X and Y location of the master (m) and the respective slave (A and B) stations:

$$A = Y_m - Y_A \qquad \Delta = AD - BC$$

$$B = Y_m - Y_B \qquad A' = A/\Delta$$

$$C = X_m - X_A \qquad B' = B/\Delta$$

$$D = X_m - X_B \qquad C' = C/\Delta$$

$$R_A^2 = X_A^2 + Y_A^2 \qquad D' = D/\Delta$$

$$R_B^2 = X_B^2 + Y_B^2 \qquad E' = R_A^2 - R_m^2$$

$$R_m^2 = X_m^2 + Y_m^2 \qquad F' = R_B^2 - R_m^2$$

The six constants, which are unique for each pair of slave stations, are stored for use in computing the Cartesian coordinates (X and Y) of the way points and present position. This completes the preliminary computations, which are done only once during each execution of the navigation program.

The way point loop is entered at this time by first referring to the way point library for TDA, TDB, and bearing angle to the way point. The bearing angle is stored for later use. Using TDA and TDB, the X and Y coordinates of the way point are computed and stored in the extended memory as the destination, X_D and Y_D.

The coordinate conversion algorithm assumes that (a) the Loran-C lines of position form a family of plane hyperbolas tangent to the earth's surface, and (b) the velocity of propagation, V_p, is constant. By using the six previously computed constants, a pair of TD's, an absolute emission delay for each station (i.e., AEDA and AEDB), and the velocity of propagation, a pair of Cartesian coordinates, X and Y, are computed for each pair of TD's, as follows:

$$\mu_A = V_p(\mathrm{TDA} - \mathrm{AEDA})$$

$$\mu_B = V_p(\mathrm{TDB} - \mathrm{AEDB})$$

$$E = \mu_A^2 - E'$$

$$F = \mu_B^2 - F'$$

$$\beta = D'\mu_A - C'\mu_B$$

$$\delta = A'\mu_B - B'\mu_A$$

$$\alpha = \frac{D'E - C'F}{2}$$

$$\gamma = \frac{A'F - B'E}{2}$$

$$\xi = (\alpha - Y_m)^2 + (\gamma - X_m)^2$$

$$\xi = \beta(\alpha - Y_m) + \delta(\gamma - X_m)$$

$$\eta = \beta^2 + \delta^2 - 1$$

$$\theta_m = \frac{\xi}{-\xi - \xi^2 - \xi\eta}$$

$$X = \gamma + \delta\,\theta_m$$

$$Y = \alpha + \beta\,\theta_m$$

The St. Marys River Loran monitor station (46° 28.1244'N, 84° 17.9343'W) has been selected as the point of tangency (i.e., coordinate center) as it is very near the geographic center of the St. Marys River.

At this point, the navigation loop (see Fig. 21) begins. Using the same coordinate conversion algorithms as before, an X and a Y are computed for the present position (X_{pp} and Y_{pp}) on the basis of TD's from the interface unit. Using X_{pp} and Y_{pp} from the previous machine cycle, which were determined as an accurate previous position, velocity dependents ΔX and ΔY are added to obtain the dead reckoning X and Y (X_{DR} and Y_{DR}). The difference between the present position and the dead reckoning position is compared with some fixed tolerance (e.g., DR window). If the difference is less than the tolerance, the present Loran position is assumed to be correct. Velocity is updated only if the present Loran position is assumed correct. If the difference is greater than the tolerance, then the Loran position is assumed to be incorrect, and the dead reckoning position is used. Whichever position is assumed to be correct is used in any further calculations in the loop.

Using the position that was just computed relative to the way point and true north, a coordinate rotation to the bearing angle of the centerline of the channel is performed. Since a finite amount of time is required to perform these calculations, the position just computed is corrected for lag based on present speed. The position plus lag is then transformed into ATD and CTE. Likewise, the velocity is transformed into ATS and CTS. As these numbers are computed, they are displayed on the bridge display and interface unit. Using the ATS and ATD, the time to go (TTG) until the boat is at the desired destination is computed. It should be noted that, since the speed is used, TTG is based on maintaining present speed. Speed is true speed relative to the bottom, including set and drift, and is displayed in statute mph or ft/s.

Only two output functions remain to be updated in this cycle. The bridge digital readout is interrogated as to desired data and those data are then displayed. The X-Y plotter is also updated with the new ATD and CTE. This completes the computations and displays for the navigation loop. The loop will repeat until the ship is at the way point.

It is determined if the ship is at the way point by examining the ATD. If the ATD is not negative, it is assumed the ship is not at the way point, and the navigation loop is repeated. If the ATD is negative, it is assumed the ship has passed the way point, and the next way point is desired. The way point number is therefore incremented by one, and the pen on the plotter is moved

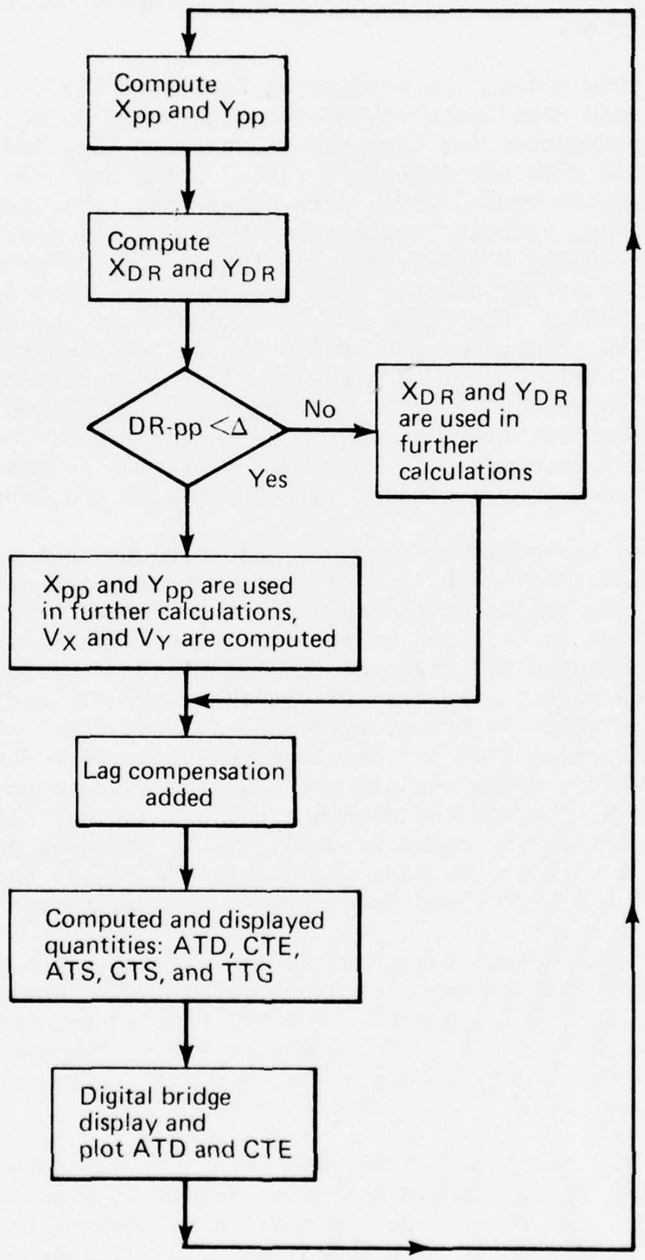

Fig. 21 Navigation Loop

down a fixed distance. (Should the pen be told to move off the bottom of the page, it will instead go to the top of the page. If a new page is not inserted, it will plot on top of previous graphs.) After these updates, the program returns to the segment that looks up way point information and reenters the navigation loop.

4.5 TURN-ON PROCEDURE

4.5.1 Lock-Up Loran-C Receiver

Using the Loran Receiver Operator's Manual,* the receiver is locked on the proper stations (near Whitefish Bay, X and Z are preferred; near De Tour Passage, X and Y are preferred). Fifteen to 30 min should be allowed for receiver warm-up before using COGLAD for navigation, especially in cold weather.

4.5.2 Power On

1. Turn extend memory OFF/ON switch to ON.

2. Turn calculator power OFF/ON switch to ON.

4.5.3 Initialize Interface Unit

1. Adjust the DIM switch for desired brightness.

2. Press the MASTER RESET switch and observe the brief (0.8 s) lamp test.

4.5.4 Initialize Calculator†

The following switches above the keyboard are set to these positions:

Degrees/Radians: to Degrees
Floating/Fixed Point: to Fixed Point
Program/Run: to Run
Decimal Digits: to 3

NOTE: If there is no display after a warm-up of 20 s, or if there is a flashing display, or if no key works, press the STOP button. The procedure can then be continued.

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*Operation, Installation, and Maintenance for Receiver Set LORAN DL-91, Navigation Systems, Inc., 15 September 1975.
†Hewlett-Packard Calculator Model 9100B Operating and Programming Manual, Part No. 09100-90021, September 1969.

4.5.5 Calibrate X-Y Plotter

1. Mount a sheet of $8\frac{1}{2} \times 11$ in. (or larger) graph paper on the plotter, press STOP on the calculator, and adjust the X and Y origin controls to position the pen at the lower left-hand corner of the graph.

2. Enter 0 in the Y register and 3000 in the X register, then press FMT and ↓. Using the X vernier control, position the pen 6 in. to the right of the origin and press STOP.

3. Enter 3000 in the Y register and 0 in the X register, then press FMT and ↓. Using the Y vernier control, position the pen 6 in. above the origin and press STOP.

4. Remove the graph paper and do not readjust the X and Y vernier controls.

4.6 OPERATING PROCEDURES

The procedures given in this section enable the operator to load the software into and operate the COGLAD system for the purpose of navigation. Once the operator has loaded the software into COGLAD, he does not have to repeat the operation unless the program and/or library contents of COGLAD are altered. Normal Power Off does not affect the software in COGLAD. In summary, once the software is loaded in COGLAD, the normal operating procedure is that given in Subsections 4.6.3 and 4.6.4, provided the proper way point library is in the extended memory.

4.6.1 Loading Navigation Program into Extended Memory

COGLAD is initialized by performing the following instructions on the calculator:

Press STOP

Turn Memory Protect Switch to OFF on extended memory

CLEAR

FMT

SET FLAG

Perform the following set of instructions to load programs 11, 21, 22, 31, 41, 42, 43, 51, 61, 62, 71, 72, 73, 74, and 00 into the extended memory, beginning with 11 and following the sequence on the memory map in Appendix A:

Insert card in calculator

ENTER

END

XX   Enter program number (11, 21, 22, 31, etc.)

FMT

FMT

(XXX) Calculator will display number of last location used in extended memory; check this against the memory map.

Using Table 5, load the constants into the extended memory with the following instructions:

(   ) Enter constant per Table 5.

↑

(   ) Address of constant.

FMT

y → ( )

After all the constants have been loaded, the memory protect line is moved with the following instructions:

117

FMT

SET FLAG

Program 81 is loaded using the instructions specified above for loading programs.

4.6.2 *Loading Way Point Library into Extended Memory*

In order to load all of the way point library, the memory protect switch on the extended memory must be OFF. The memory protect line is then moved to the first address where the library begins. This procedure is followed:

118

FMT

SET FLAG

To load the program from magnetic cards, which will transfer the library from the calculator to the extended memory, these instructions are followed:

CLEAR

GOTO

-

0

0

Insert magnetic card containing program in read slot.

ENTER

The program is now in the calculator. To load data from magnetic cards, the pertinent magnetic card is entered in the read slot. To enter into calculator, these instructions are followed:

Insert card with segment of way point library

END

ENTER

To transfer data from the calculator to the extended memory, the first address in the extended memory is entered in the X register. At this point the program is ready to make the transfer. The instructions are

118

CONT

At this point, the calculator will stop with the first address in the Z register, the last address in the X register, and the data that went to the last address in the Y register. The transfer of 14 entries from magnetic card to the extended memory way point library section has just taken place. In order to transfer the remaining entries into the way point library, the following are entered:

END

Insert the magnetic card with the segment of the way point library

ENTER

FIRST ADDRESS FOR DATA SET

CONT

This procedure is continued until the entire way point library is entered in the extended memory. The memory protect line is then set at address 222 with the following instructions:

222

FMT

SET FLAG

The extended memory memory protect switch is turned ON.

4.6.3 Load Graph Paper on Plotter

Graph paper to be used on the X-Y recorder is inserted, STOP is pressed, and the X and Y origin controls are used to position the pen to the starting point on the paper, i.e., 1 in. from the top and 2 in. from the right.

4.6.4 Operating Procedure for Navigation Program

The COGLAD system will operate in an automatic mode after the following instructions are performed:

CLEAR

FMT

GOTO

XX — Way point number of first way point

CONT

The navigation program will start at this point and continue until the operator executes the STOP instruction. If the plotter is enabled, the paper should be changed after every three legs or the plotter will plot on top of previous plots.

If the printer registers are enabled, the output will be as shown in Table 7. The data will be printed as long as the X and Y print registers are enabled. The Z register is not needed. The only deviation from the form shown in Table 7 is in the beginning of the navigation program when one additional set of TD's are printed.

Table 7

Printer Output Format

Example	Explanation
3.3178837 07	TDA in ns
1.1264251 07	TDB in ns
- 64.331	CTE in ft
0.587	ATD in mi
0.605	CTS in ft/s
7.735	ATS in mph

5. RESEARCH CAPABILITIES OF COGLAD

5.1 INTRODUCTION

The COGLAD system is a powerful research tool that can be used in numerous ways to fine tune the system and to establish way point time differences. A number of special-purpose programs provide the means of using, changing, checking, and simulating various aspects of the system. The statistical mode is used primarily to measure and evaluate the TD's of a way point. The position jitter program is used to measure total system instability from the transmitter to final processing. It is possible to expand the scale of the navigation program's plot to obtain a plot of a maneuver using the track plot mode. Should the minichain be off the air for any reason, it is possible to check out COGLAD in the simulation mode. In the event a way point changes or a new one is added, the COGLAD system is able to perform the necessary calculations and editing to the existing way point libraries to incorporate such changes. Appendix A contains the software listing for the various programs.

5.2 STATISTICAL PROGRAM

The statistical program examines the TD's from the interface unit and plots the change from the first pair of TD's read. This loop is repeated continuously until it is manually terminated by the operator. When the program is terminated, the average and standard deviation of TDA and TDB are computed and printed.

The program is stored on a magnetic card and is entered into the calculator by pressing

CLEAR

END

The magnetic card is inserted into the calculator with the "A" side down and the ENTER button is pressed. The "B" side is inserted and ENTER pressed. STOP is then pressed.

Graph paper is placed on the X-Y plotter and the STANDBY/ENABLE switch is turned to ENABLE. Using the X and Y origin knobs, the pen is positioned to the left-hand margin and on a horizontal line approximately one-quarter of the distance down the paper.

The printer is enabled by pressing the following switches:

ON

X

Y

Z

When the receiver is locked up and settled on the slave stations to be montiroed, the program is started by pressing:

CONT

The plotter will now plot the TDA change on the top line and the TDB change on the bottom line.

The program is stopped by pressing

STOP

SET FLAG

CONT

The calculator will now compute the average and standard deviation of TDA and TDB and print them on the printer.

The program is restarted by pressing

END

CLEAR

CONT

5.3 POSITION JITTER PLOT PROGRAM

The position jitter plot program is designed to plot the apparent position on a greatly enlarged scale. Plotting the apparent position change while the boat is secured to a dock results in an easily understood record of total system drift, from the transmitter through final COGLAD processing. Typically, a scale of 10 to 20 ft/in. on each axis is used.

The position jitter plot program consists of the navigation program with a few modifications, which are stored on magnetic cards. When either program is loaded in the extended memory, the following instructions will change from the navigation to the jitter plot program or vice versa:

Turn memory protect switch OFF.

STOP

END

Insert card in calculator for 71 of desired program.

ENTER

END

7

2

FMT

SET FLAG

7

1

FMT

FMT

74	JITTER	Calculator's response
77	NAVIGATE	

END

Insert card for 73 of desired program.

ENTER

END

8

0

FMT

SET FLAG

7

3

FMT

FMT

86 — Calculator's response

END

Insert card for 0 of desired program.

ENTER

END

9

0

FMT

SET FLAG

0

FMT

FMT

99	NAVIGATE	Calculator's response
97	JITTER	

2

2

2

FMT

SET FLAG

Turn memory protect switch ON.

With a piece of graph paper on the X-Y plotter, the STANDBY/ENABLE switch is placed in ENABLE. Using the X and Y origin knobs, the pen is positioned in the center of the paper. When the receiver is locked up and settled on the slave stations to be monitored, the program is started by pressing

CLEAR

FMT

GOTO

97 — Calculator's response

X

X Number of samples

X

X → ( )

\-

e

X Way point number

X

CONT

The position jitter plot program will start to run at this point. The calculator will stop normally with 0 in the X and Y registers. Any other contents cause an abnormal stop.

To restart the program for any reason, the above instructions should be followed.

5.4 TRACK PLOT PROGRAM

The track plot program is a combination of the navigation and position jitter plot programs designed to study the local distortion of an area. Plotting the position of the vessel on an enlarged scale when the speed of the vessel is relatively slow permits study of local distortion due to the environment. Typically a scale of 100 ft/in. cross track and 500 ft/in. along track is used.

The track plot program consists of the navigation program with a part of the position jitter program plus a modification. With the navigation program loaded in the extended memory, the executive, program 00, is replaced by the position jitter executive program, stored on a magnetic card, by performing the following:

Memory protect switch OFF.

9

0

FMT

SET FLAG

END

Insert card for 00 of position jitter.

ENTER

END

CLEAR

FMT

FMT

The only other change is to program 73. The following steps will change the plot scale:

7

3

FMT

GOTO
END
GOTO
5
d
PROGRAM/RUN: switch to PROGRAM
5
2
8
0
CHG SGN
X
↓
FMT
↓
FMT
END
PROGRAM/RUN: switch to RUN
END
8
0
FMT
SET FLAG
7
3
FMT
FMT
2
2
2
FMT
SET FLAG
Memory protect switch ON.

With the receiver locked up and the plotter pen positioned in the center of the page, the following instructions will begin the program:

CLEAR

FMT

GOTO

CLEAR

CONT

The resultant plot will have true north at the top of the page and a plot of a particular area.

The program will continue to run until stopped by the operator. To restart the program the operating instructions given above should be followed.

5.5 MODIFYING A WAY POINT LIBRARY

Modifications to any of the way point libraries are carried out by a multiphase operation. First, the new or corrected TD's for all three stations (TDX, TDY, and TDZ) are stored in the appropriate registers of the extended memory. Next, two new bearing angles, the bearing angle to the corrected way point and the bearing angle to the next successive way point, are computed and stored in the extended memory. The final phase is to update the magnetic cards containing the way point library.

The prerequisite for performing a change to the library is that the proper way point library be loaded in the extended memory. Typical changes are either the addition of a new way point or the revision of a way point's TD's. In either case, the new TD's are entered into the way point library in the extended memory.

5.5.1 Computing a Bearing Angle

To change the navigation program, the computation of the bearing angle by COGLAD uses the navigation program with a few modifications that permit the operator to perform only this task. The navigation executive (00) is changed in the extended memory as follows:

Address	From	To
2.b	FMT (42)	5 (05)
2.c	ACC- (63)	FMT (42)
2.d	PRINT (45)	GOTO (44)
3.0	↑ (27)	PRINT (45)

A new program (5) is written as follows:

0.0	X ← ( )	67
0.1	-	34
0.2	b	14
0.3	↑	27
0.4	X ← ( )	67
0.5	-	34
0.6	a	13
0.7	↑	27
0.8	FMT	42
0.9	END	46

This program is labeled as 5 and stored in register 221. Incidentally this destroys the bearing angle of the last way point which must be replaced later.

Program 72 is modified as follows:

Address	From		To	
0.3	X↔Y	(30)	STOP	(41)

The program is operated as follows:

TDA and TDB of the previous way point are stored in locations -a and -b, respectively, in ns. This effectively takes the previous way point as the present position.

The DL-91 receiver must be locked on to the same slave stations as stored in -a and -b, which satisfies the slave station identification and coefficient lockup subroutines in the navigation program.

Starting the navigation program as usual, the way point number whose TD's have been updated or added is selected.

The program will stop with the following display:

Z		
Y	θ	(degrees)
X	R	(000 yd)

If θ is negative, 360 is added to the number to convert it to navigation coordinates. θ is stored in the extended memory with the corresponding TD's. The procedure is then repeated with the updated TD's as the assumed present position and the next way point as destination.

5.5.2 To Store Way Point Library on Magnetic Cards

Prior to executing the transfer from the memory to magnetic cards, the handler program must be loaded in the calculator by the following procedure:

GOTO

-

0

0

Enter card in reader slot with handler program.

ENTER (button on right of reader)

To execute the program, the following steps are performed:

GOTO

-

0

0

X

X   Memory address of first data is set.

X

CONT

When the calculator stops, 14 entries from the library have been transferred from the extended memory to the calculator. To transfer these to the magnetic cards, the following steps are performed:

END

Insert card data are to be stored on
RECORD (button on left of reader).

The process is continued until the entire library is stored on magnetic cards.

5.6 SIMULATION MODE

As an aid to checking out the entire system, it is possible to modify the software navigation program to simulate actual navigation of a ship. The modifications to the software consist of having TDA and TDB computed by software where they were previously loaded by the hardware, computing an increment for TDA and TDB on each leg of the vessel's journey, and adding this increment to TDA and TDB when an update is required. With these modifications, the entire river can be traversed in any one direction provided an entire way point library is loaded in the extended memory. If only a few way points are loaded in the extended memory, it is possible to cycle through these points continuously by making another modification to the software. With these modifications incorporated into the software, execution of the program is exactly the same as normal operation in the navigation mode.

The loading of TD's into software occurs at two places. One is in the executive when TD's are loaded by the executive and passed to the subprogram that computes the present position (addresses 2b through 30 are replaced by 8, FMT, GOTO, and PRINT). This modification applies to program 8 which will cause a set of TD's stored in the calculator's memory at addresses -a and -b to be incremented by a delta that has been calculated and stored in the extended memory at addresses 190 and 191. The resultant TD's are loaded into the Y and Z registers and stored in -a and -b. The other place is in the subprogram that identifes which two of three secondary stations are being used (addresses 2d through 31 in program 11 are replaced by 5, FMT, and GOTO). This modification applies to program 11 which will cause a set of TD's that are stored in the calculator's memory at addresses -a and -b to be loaded into the Y and Z registers.

Whenever the way point library is consulted for the particulars of a way point, the present TD's and the TD's of the way point are used to compute a delta for each TD. On the basis of the range to the way point and some fixed speed, a time is computed in seconds. Knowing the amount of time required for one machine cycle (i.e., the cycle of the program), the total number of machine cycles per leg is computed. By computing the difference in TD's between present position and destination and dividing by the number of machine cycles per leg, a delta TD is computed. The delta is stored in the extended memory at addresses 190 and 191. The equations are shown below.

General	Example
$\text{Time per leg} = \dfrac{\text{Range}}{\text{Speed}}$	$\text{Time} = \dfrac{\text{Range}}{10\ \text{mph}} \left(\dfrac{60\ \text{min}}{\text{h}}\right)\left(\dfrac{60\ \text{s}}{\text{min}}\right) = 360\ \text{range}$
$\text{Total number machine cycles per leg} = \dfrac{\text{Time per leg}}{\text{Time/machine cycle}}$	$\text{Number machine cycles} = \dfrac{360\ \text{range}}{6.5\ \dfrac{\text{s}}{\text{machine cycle}}} = 51.4\ \text{range}$
$\Delta\text{TDA} = \dfrac{\text{TDA} - \text{TDA}_{pp}}{\text{Total number machine cycles per leg}}$	$\Delta\text{TD} = \dfrac{\text{TDAD} - \text{TDA}_{pp}}{55.4\ \text{range}}$

The modifications to the software for this change consist of inserting instructions at the end of way point lookup subprogram 31 which calls subprogram 6 which performs the above outlined steps (addresses 47 through 4b of program 31 are replaced by 6, FMT, GOTO, FMT, and END).

Should only a few way points be loaded in the library and cycling through these few points is desired, comparison of the way point number with a limit will achieve the purpose. The limit is equal to the highest way point number to be called plus one. When the way point number equals the limit, the number is reset to one. Otherwise, do nothing and continue with normal operation. The modifications to the software consist of inserting instructions at the beginning of the way point lookup subprogram 31, which refers to the steps outlined above, subprogram 4.

These modifications to the software replace the TD information obtained from the interface unit. If the entire system is up and running, the modifications do not change normal operations during execution of the navigation mode.

The subprograms referred to above are listed in Appendix A and summarized in Table 8. Before operating the simulation mode, each of these programs is loaded in the extended memory either from magnetic cards or by entering the instructions from the keyboard. If the latter, the PROGRAM/RUN switch must be in the PROGRAM position and the program pointer at location 00 before beginning the program. Each program is loaded in the extended memory using the following instructions:

Table 8

Simulation Programs

Program Number	Location in Extended Memory	Acronym	Title	Function
4	192-194	CYCLE	Cycle	Cycles navigation program through any given number of way points.
5	195	LTDAB	Load TDA and TDB	Loads TDA and TDB into Y and Z registers.
6	196-199	ΔTD	Compute ΔTDA and ΔTDB	Computes increment for TDA and TDB for each leg.
8	200-201	ITD's	Increment TDA and TDB	Increments TDA and TDB by ΔTDA and ΔTDB and stores results.

Turn memory protect switch OFF

XXX — Enter number of first location in extended memory for the program.

FMT

SET FLAG

XX — Enter number of program.

FMT

FMT

When all these programs have been loaded in the extended memory, the following is performed:

222

FMT

SET FLAG

Turn memory protect switch ON.

The simulation program operates in the same manner as the navigation program. The instructions outlined in Subsection 4.5 are performed after the TD's of the assumed present position are entered in -a and -b.

6. WAY POINT

6.1 INTRODUCTION

A way point can be compared to a buoy in that both are fixed, geographically defined reference points that can be used by all vessels. All way points for traversing the St. Marys River have been established and measured.

6.2 DEFINITION

A way point is defined as the intersection of the centerlines of two adjacent channels (see Fig. 6). To describe a way point for COGLAD calculations, the TD's of the way point are needed. The heading angle for a particular channel is calculated using the COGLAD algorithms and the TD's of the way point at each end of that channel. Each channel is described by the TD's and heading angle.

Each route through the St. Marys River can be described by a series of line segments running down the center of the channel. Since each channel is described by the TD's of a way point and heading angle, each route is described by a set of such data.

Whereas a way point is a fixed point, a turning point is not. A turning point always occurs before a way point. Its location varies with the speed and maneuverability of the boat, the current, the wind, and the individual pilot.

6.3 ROUTES

Four routes are used by the ore carriers in traversing the St. Marys River during the year. In terms of the definition given previously for a route, the routes are

Downbound summer (south) — 24 way points

Downbound winter (south) — 26 way points

Upbound summer (north) — 25 way points

Upbound winter (north) — 26 way points

Many way points are common to more than one route; thus, there are only 34 unique way points among the four routes.

The exact TD's and bearing angle for each way point have been measured by COGLAD using the statistical mode, with a Coast Guard vessel hove to at each way point. The measured data are listed in Appendix B along with the geographical location of each way point.

7. TEST RESULTS

7.1 INTRODUCTION

From January through June 1976, APL personnel supported field test operations on the St. Marys River and at the Coast Guard Electronics Center at Wildwood, New Jersey. All field operations were coordinated and conducted with the Coast Guard; the test dates and objectives are given in Table 9.

Most of the testing was done aboard the Coast Guard cutter Naugatuck, a 110-ft harbor tug normally used for icebreaking during the winter season. Except for a 4-week maintenance period, the Naugatuck was assigned exclusively to the mini-Loran program. The exclusive availability of the vessel was a distinct asset to the program, and the cooperation from the crew was outstanding.

Table 9

Field Operations

Date (1976)	Location	Objective
12-28 January	Sault Ste. Marie, MI	Install and test COGLAD. Preliminary grid calibration and way point measurement.
16-19 February	Wildwood, NJ	Testing with simulator. Evaluate COGLAD with AN/SPN-45 and DL-91 receivers.
16-17 March	Wildwood, NJ	Testing with simulator. Evaluate COGLAD with modified DL-91 receivers.
25 March-9 April	Sault Ste. Marie, MI	Preparation and support for demonstration. Measure additional way points.
17-21 May	Sault Ste. Marie, MI	Compile way point libraries. Evaluate way point data and grid distortions. Coordinate Buckthorn installation.
16-19 June	Sault Ste. Marie, MI	Evaluate way point data and grid distortion. Train Coast Guard personnel.

7.2 LORAN-C SIMULATOR TESTING

As a result of field tests on the St. Marys River in January 1976, COGLAD and all of the monitor station receivers were shipped to the Coast Guard Electronics Center in Wildwood for calibration and evaluation of the Loran-C simulators.

Two standard conditions were used for receiver testing, simulated St. Marys River and "ideal." The simulated St. Marys River conditions, based on measurements made at the Riverside Monitor Station, are

Master	43 dB
Slave X	46 dB
Slave Y	50 dB
Slave Z	40 dB
Noise (gaussian)	+10 dB S/N (slave Y)
Cross rate interference (CRI)	at 9930 μs, 0 dB (slave Y)
Continuous wave interference (CWI)	at 60 kHz, -20 dB (slave Y)
Envelope/cycle discrepancy (ECD)	+ 0.7 (all stations)

Ideal conditions were the same as above but with noise, CRI, and CWI turned off.

During the first series of tests at Wildwood 16-19 February, two AN/SPN-45 receivers and a DL-91 receiver were tested. One SPN-45 was part of the St. Marys River COGLAD system, and the other, part of the old COGLAD system that had been used briefly in the monitor station. The DL-91 was modified by Navigation Systems, Inc. (DECCA), to provide the required tracking strobes for use with COGLAD.

The tests indicate that the 150-μs peak-to-peak dither in measured time differences is due to the tracking loops in the SPN-45 receiver. Cross-coupling between tracking loops was also observed, thus explaining the dither correlation between TDA and TDB. Neither the long-time constant marine AFC board (KB) or the short-time constant aircraft AFC board (K) were effective at reducing the dither, although the marine AFC board appeared to be slightly better in the presence of noise. Peak-to-peak dither on the DL-91 receiver was definitely less, and there was no noticeable

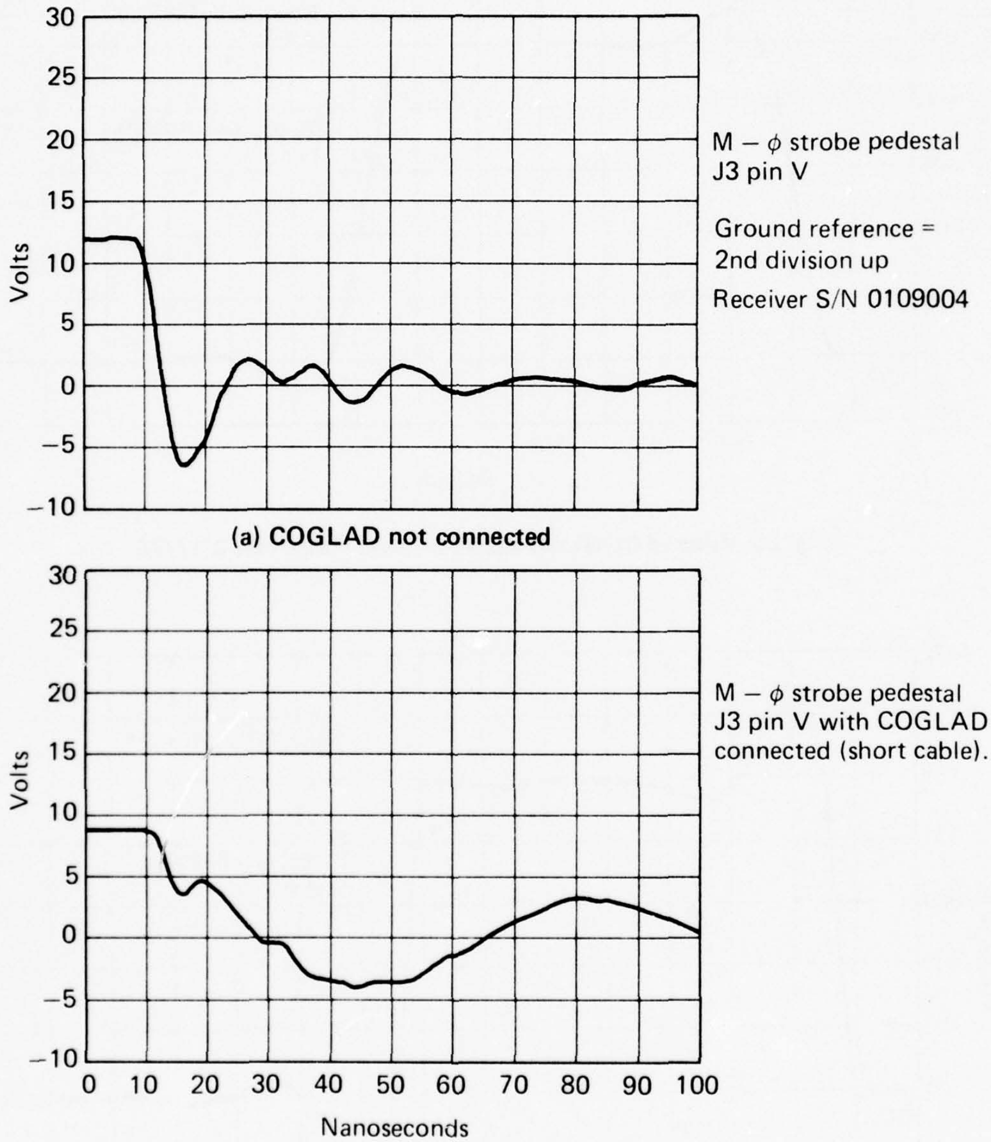
cross-coupling between tracking loops. Jitter plots were three to five times smaller using the DL-91 than the SPN-45.

During the second series of tests at Wildwood 16-17 March, two new DL-91 receivers were tested. They were modified by Navigation Systems, Inc., to be plug compatible with COGLAD (i.e., the three tracking strobes were brought out on a connector like SKT-8 on the SPN-45 receiver). However, the output impedance of the DL-91 was higher than the SPN-45, and some ringing was observed in the tracking strobes when COGLAD was connected. The innerconnect cable was shortened from about 22 to 6 ft, but there was still some ringing (see Fig. 22). The ringing did not appear to affect the timing accuracy. Standard deviations of the TD's measured by COGLAD were always consistent with standard deviations measured by the Loran signal simulator.

Despite the good-to-excellent standard deviations, the jitter plots were surprisingly large (several hundred feet for St. Marys River conditions). It was concluded later that the TD's used were way beyond the normal St. Marys River coverage area and had very poor crossing angles. The Loran signal simulator cannot simulate a TD of less than 13 000 μs and the typical TD for slave X for the St. Marys River is about 11 250 μs. This is unfortunate because the preferred slave pairs are X-Z for the upper part of the river and X-Y for the lower part.

The step function response of these receivers was measured under no-noise conditions with and without the COGLAD interface filter. Figure 23 shows the results of a 1-μs step with filtering, Fig. 24 is the same test without filtering. The small jitter on the unfiltered plot is the 20-ns resolution of the TD counter circuit in COGLAD. Comparison of these plots shows that the COGLAD filter is very near optimum for the response time of this receiver. Overshoot is reduced from 34 to 10%, and settling time (to stay within ±10% of the final value) is reduced from 21.3 to 16.0 s.

A final test of the receivers was a comparison of time difference dither under dynamic versus static conditions. Dynamic testing is rarely done because of the sophisticated test system required. The Loran simulator was programmed to slew the TD's at 10 ns/s, and the statistical program of COGLAD was modified to move its TD reference numbers at 65 ns/machine cycle. This very nearly synchronized the two systems at a simulated speed of about 7 mph. Figure 25 is a plot of the change in TDA and TDB versus time, with and without noise. The slight slope of the graphs indicates that the two systems were not exactly synchronized. However, it was required only that they be synchronized well



(a) COGLAD not connected

(b) COGLAD connected

Fig. 22 Master Tracking Strobe

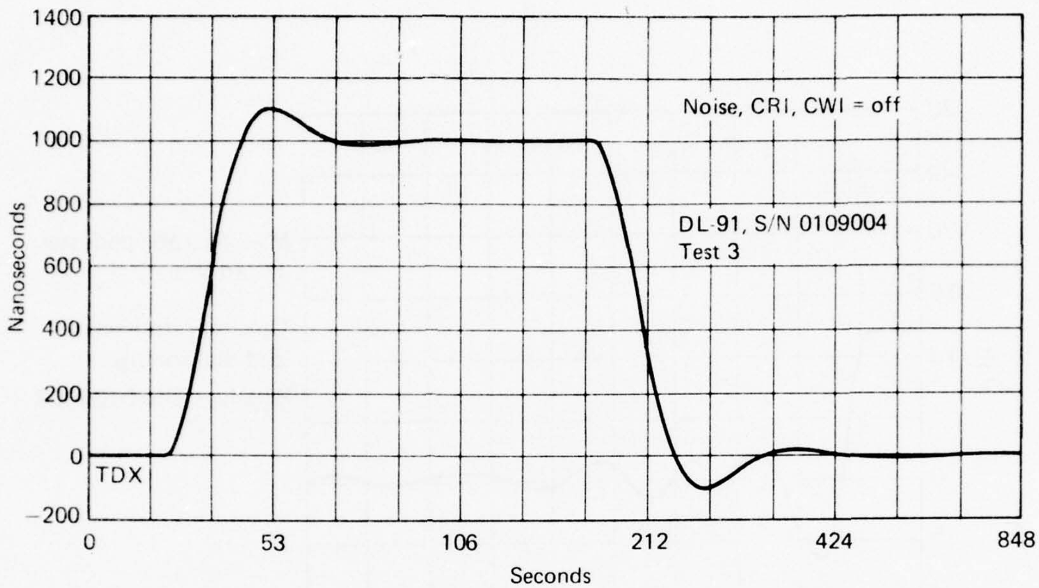


Fig. 23 Filtered COGLAD Step Function Response, 3/17/76

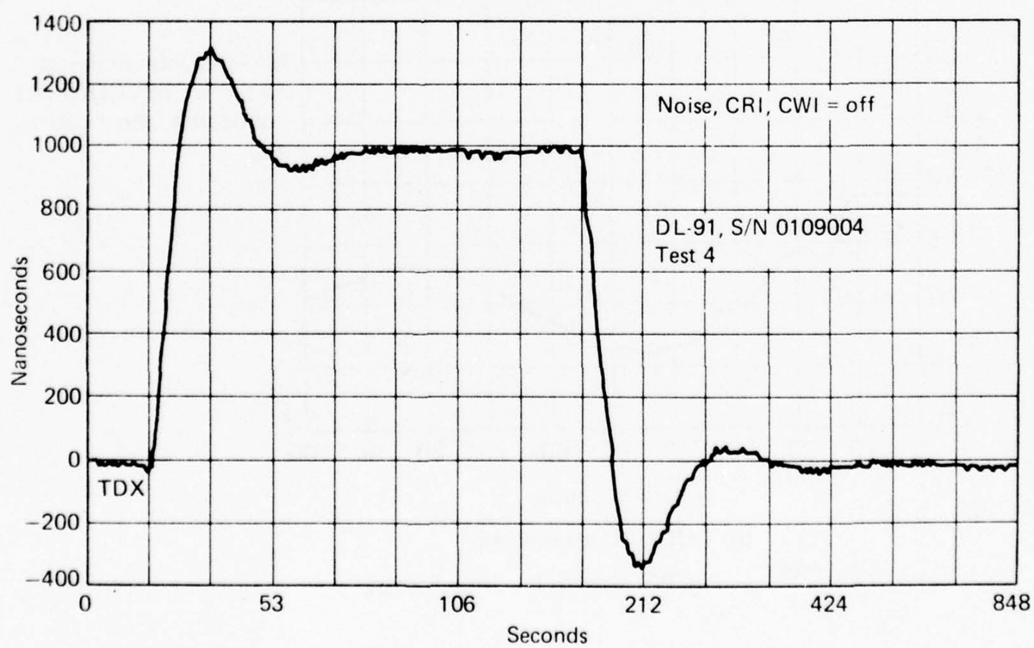


Fig. 24 Unfiltered COGLAD Step Function Response, 3/17/76

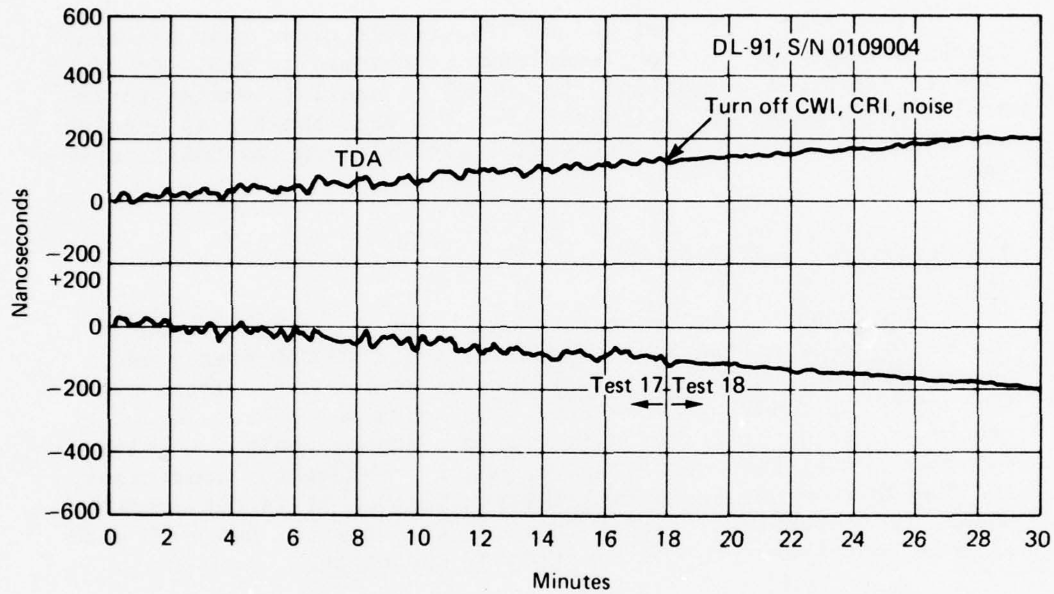


Fig. 25 Change in TDA and TDB versus Time, 3/17/76

enough that the plotter not go off scale in the vertical axis. The vertical axis scale is 20 ns/minor division. The test indicates that the receiver tracking loops dither at least as much under dynamic conditions as under static conditions.

The DL-91 receivers had no discernible cross talk between tracking loops and were not sensitive to changes in ECD. In addition to its other advantages, the DL-91 is smaller, easier to install and operate, and quicker to lock up than the SPN-45 receiver. Switching to a DL-91 receiver definitely improves the COGLAD system.

7.3 STABILITY MEASUREMENTS

Numerous stability measurements were made during each of the field tests on the St. Marys River. The COGLAD system made the measurements while the Naugatuck was stationary. Total system noise and drift were measured, including the effects of cesium standards drift, transmitted wave shape, monitor station equipment, minichain operating personnel, propagation conditions, and COGLAD receiver and oscillator stability. It is not possible, under the constraints of this testing, to determine how much each element contributes to the total noise and drift.

Two different programs, statistical and position jitter plot, are used in making stability measurements. The statistical program plots the change in measured time differences at about 3-s intervals. Since the boat is stationary at this time, any change in TD's results from either noise or drift. When the program ends, COGLAD prints the average, standard deviation, and number of samples for each TD. Figure 26 is a plot of M-X and M-Z time differences measured while the cutter was in its slip at Sault Ste. Marie. Short-term (2 to 30 min) standard deviations of 4 to 10 ns were normal at Sault Ste. Marie, while slightly smaller numbers were usually measured 8 to 10 mi downstream.

Long-term stability (critical to the success of the minichain) was not measured because the stations were rarely kept in tolerance more than 8 h/day because of a shortage of watch standers and delays in installing telephone modems to each of the transmitters.

The position jitter program plots a position fix approximately every 6.5 s using a modified version of the navigation program. Plotting a series of 25 or 50 fixes to a scale of 20 ft/in. provides a graphic display of position jitter. Circles containing 95% of the plotted fixes ranged from about 15 to 30 ft in diameter.

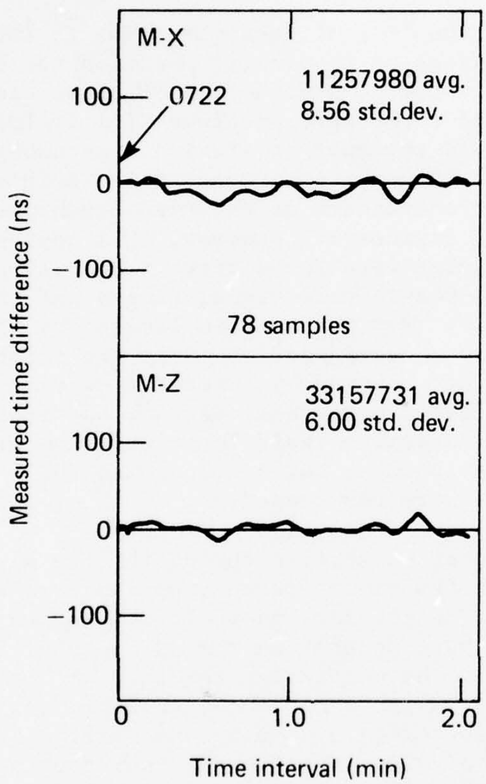


Fig. 26 Statistical Plot of M-X and M-Z at Sault Ste Marie, 6/18/76

It was not possible to make day-to-day comparisons of the mean offset of the circles from some known point because the transmitters and monitor station were still in the testing and tuning stage.

7.4 WAY POINT MEASUREMENT

To determine the TD's of each way point to the required precision, it was necessary to physically position the boat over the way point and measure the TD's with the COGLAD statistical program. The process presented a two-part problem: (a) to locate the way point, and (b) to hold the boat on station long enough to measure the TD's (about 5 to 10 min). The Coast Guard originally planned to place Autotape* transponders on surveyed bench marks established by the Army Corps of Engineers. However, this approach was abandoned when discrepancies were found between the way point locations as determined by the Coast Guard visual ranges and the Corps of Engineers bench marks. Way points were located by lining up intersecting visual ranges where possible. Some way points (especially in open water) were not covered by intersecting visual ranges, and it was necessary to use a horizontal sextant and angles scaled from a 1:40 000 chart to determine their location. The procedure was adequate for most way points, but the locations of a few were suspect even after they were resurveyed.

Holding the boat on station during the ice season was simple and effective. With the river frozen from shore-to-shore, the cutter could be stopped in the ice and would remain stationary for hours. Holding the boat on station for even a short time after the ice broke up proved to be nearly impossible. With a 2- to 5-mph current and a 20- to 30-mph wind, the boat could not remain on station even with the anchor down. Heavy ore carrier traffic, except during the ice season, also interferred with stopping on the way points to make measurements.

After the way points were measured, COGLAD was used to compute the range and bearing between consecutive way points, which were then compared to the range and bearing obtained from the charts. Table 10 is a comparison of the measured bearing angles and the angles from the charts. The larger mean errors are based on the absolute values of the errors, and the smaller mean errors are the algebraic values of the errors. The low mean values obtained by this comparison indicate that the combined effects of Loran grid bias and coordinate transformation bias are minimal.

*A line-of-sight radio ranging device used as a reference.

Table 10

COGLAD Bearing Angle
Compared with Bearing Angle from Charts

Route	Type of Average*	Mean*		Standard Deviation	
Downbound, Summer	Avg $\|\Delta\theta\|$ Avg $(\Delta\theta)$	0.49° -0.10°	0.14% 0.3%	0.30° 0.57°	0.08% 0.16%
Downbound, Winter	Avg $\|\Delta\theta\|$ Avg $(\Delta\theta)$	0.46° -0.07°	0.13% 0.02%	0.26° 0.53°	0.07% 0.15%
Upbound, Summer	Avg $\|\Delta\theta\|$ Avg $(\Delta\theta)$	0.42° 0.01°	0.12% 0.003%	0.26° 0.50°	0.07% 0.14%
Upbound, Winter	Avg $\|\Delta\theta\|$ Avg $(\Delta\theta)$	0.48° 0.10°	0.13% 0.03%	0.28° 0.56°	0.08% 0.15%

*Larger values are based on absolute error values, lesser on algebraic.

7.5 GRID DISTORTIONS

Tests were conducted to evaluate static and dynamic Loran grid variations and grid deviation. As was expected, significant variation was observed while passing under the International Bridges at Sault Ste. Marie. The effect of these bridges was observed for 800 to 1000 ft. Little or no variations were observed from structures in the Soo Locks.

Variations were also observed in some of the channels in the river, especially in the vicinity of Neebish Island. These channels were traversed in both directions to verify the consistency of the distortions. Mid-channel errors as great as 100 ft were observed in the cross-track axis. Figure 27 contains four track plots of a section of the West Neebish Channel just upstream of Coast Guard Lookout Station No. 4. Power lines were observed on the western shore, directly between the boat's position and the slave X (Pickford) transmitter. The geometry for this portion of the river is such that any distortions in slave X (also in the master station) would translate, almost entirely, into the cross-track axis rather than the along-track axis.

Contrary to expectations, no dynamic variations in the Loran grid were observed when other vessels passed nearby, sometimes with

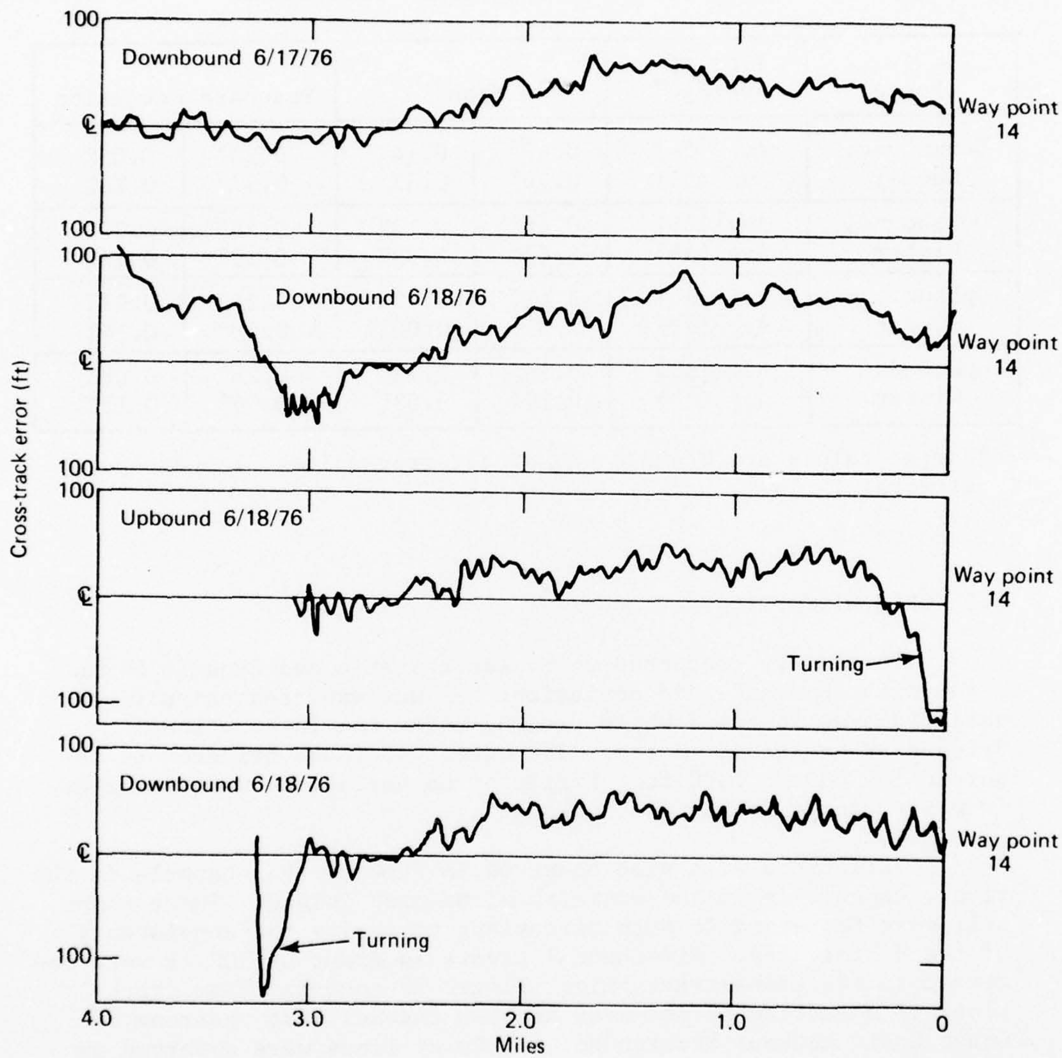


Fig. 27 West Neebish Channel North of Coast Guard Lookout Station No. 4

as little as 90 ft between hulls. For maximum sensitivity, this test was usually run with the Naugatuck stopped in the ice and the statistical program running while the other vessel passed.

To evaluate grid deviation, the boat executed a cloverleaf pattern around a marker buoy. Autotape data were recorded while COGLAD plotted the boat's track. Unfortunately, the Coast Guard was not able to determine the boat's track accurately from the Autotape data, so the test was inconclusive except to indicate that there were not gross deviations.

7.6 COGLAD COEFFICIENTS TUNEUP

The velocity filter coefficient (K_5) and the position lag coefficient (K_6) were empirically adjusted in the field for optimum performance. After the adjustment, the velocity determined by COGLAD consistently agreed with independent velocity measurements to within 0.1 mph. It was possible to adjust the position lag coefficient for virtually zero lag (at the instant of display update) and still have an acceptable position overshoot during a turning maneuver. The success of these adjustments was due mostly to the high S/N and the high TD resolution (20 ns) of the COGLAD system.

7.7 BRIDGE DISPLAY

A special bridge display (described in Section 3) was developed for the St. Marys River version of COGLAD. The display is a compromise between what APL considers an optimum system and existing hardware, time, and funding constraints. Evaluation of the unit was not as extensive as originally expected because the Coast Guard elected not to exercise Phase III of the program, evaluation aboard a commercial ore carrier. Nevertheless, numerous observations and comments about the effectiveness of the display were obtained, mostly from Coast Guard shipboard personnel.

Most of the users seemed to prefer the horizontal light dot used in the analog presentation of the CTE, although a few users seemed to think a digital readout would be better. All agreed that the scale markings, the lighting, and the "X10" light could and should be improved. Updating the display more often than its 6.5-s rate would also improve the continuity-of-motion feeling.

The analog ATD and the ATS displays were acceptable to most users, but digital display registers might have been better. The analog ATD display lacked the desired resolution approaching a way

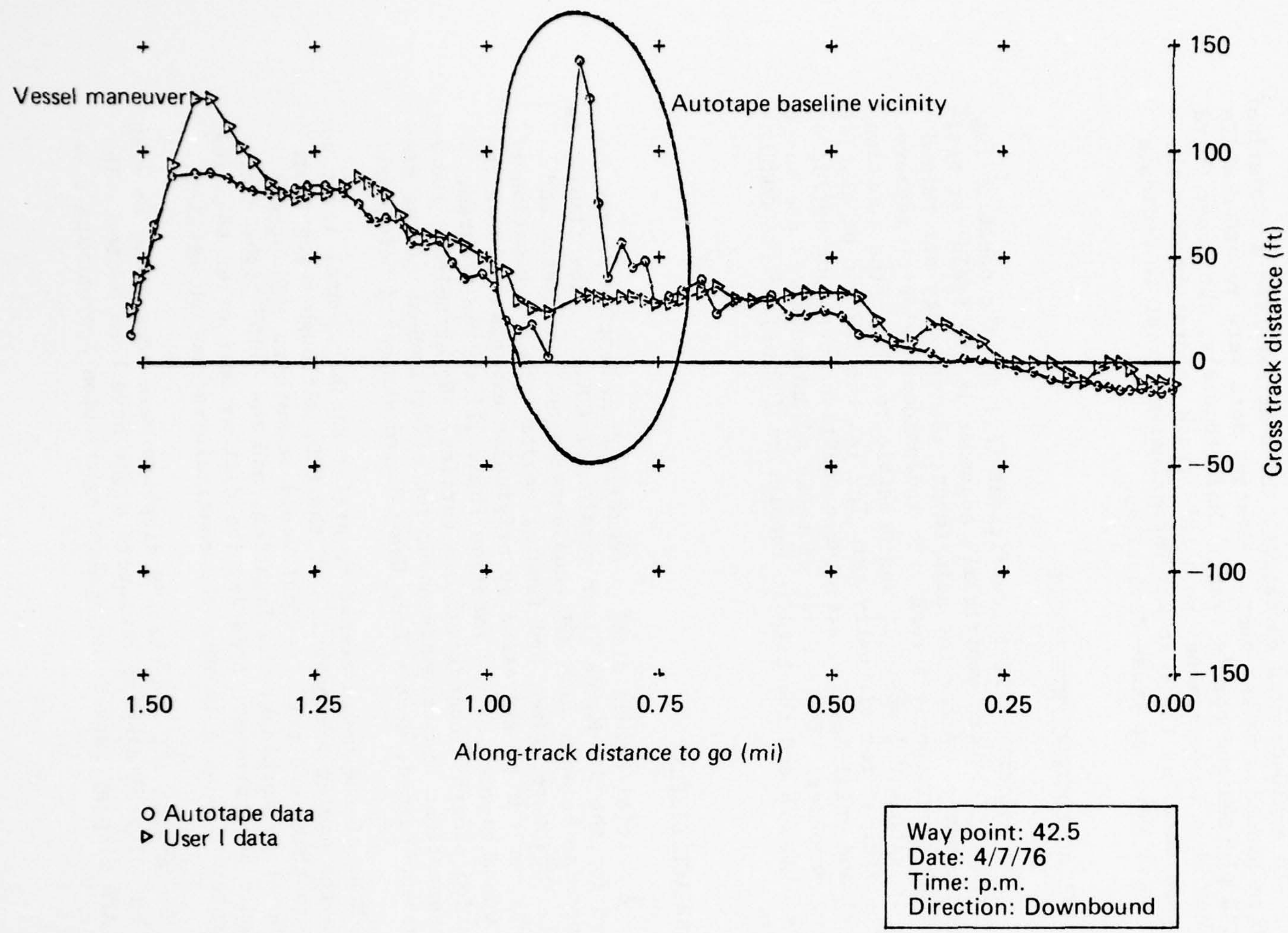


Fig. 28 Track Plot of COGLAD and Autotape Position Data

point (i.e., ATD of less than 1 mi) and the digital display was usually read instead. On the St. Marys River, speed limits are rigidly enforced, and the difference between 12.0 mph and 12.1 mph is important. For this reason, a digital display would probably be better for ATS.

The analog CTS was included on the bridge display as an experiment to determine if the quality of the data would be good enough to be usable and if the helmsmen would use the display to anticipate the necessary rudder commands. While some jitter was noticeable, the display was usually a reliable indication of the boat's CTS relative to the bottom. Many of the helmsmen appeared to ignore the CTS display, but some began to use it as a qualitative guide to rudder commands and seemed to think it rather helpful.

7.8 DEMONSTRATION AND EVALUATION RUNS

Many track plots were recorded by COGLAD system, but unfortunately, there is very little recorded reference data to evaluate the plots. The Coast Guard's plans to use Autotape as a reference system did not work out as well as expected. Most of the time, the only references for comparison were the visual ranges and seaman's eye. While most of the seamen were quite accomplished at steering a range line, the procedure left no permanent record for post-mission analysis. One enterprising Coast Guard Reserve officer used a tape recorder to record comments every 0.25 mi, but this was still a rather subjective approach.

During a demonstration for Coast Guard personnel on 7 March 1976, Autotape was used very effectively on about three consecutive channels of the river. Figure 28 is a comparison of COGLAD position data versus Autotape. (This plot was prepared by the Coast Guard R&D Center at Groton, Connecticut, using data taken jointly by APL and Coast Guard personnel.) The track plot was made with the Naugatuck downbound just south of Six Mile Point while the pilot was steering a visual range. The difference in cross-track position measured by the two systems is typically much less than 15 ft. The Coast Guard design goal for the entire system was to determine cross-track position with an error of less than ±25 ft 95% of the time. The track plot in Fig. 28 shows the goal was achieved with a comfortable margin. However, there are insufficient controlled data (i.e., with Autotape or other precision reference systems) to statistically verify the 95% requirement.

8. RECOMMENDATIONS

8.1 INTRODUCTION

It is APL's opinion that the test data indicate, with 80 to 90% confidence, that the minichain concept is a viable approach for piloting boats in confined waters. To improve the confidence level, more long-term stability data are needed. It must be established that the required accuracy can be maintained throughout all seasons and all forms of precipitation. Distortions in the Loran grid have been observed in some parts of the St. Marys River. These distortions must be accurately measured and the transformation algorithms modified to compensate for them.

Beyond this, additional effort will be required, both on the transmitting equipment and the user equipment, to make the St. Marys River minichain an operational navigation system. The recommendations in the following paragraphs are made by APL based on test results obtained thus far.

8.2 MINICHAIN OPERATIONAL STATUS

The St. Marys River minichain should be updated to full operational status to facilitate the necessary additional field testing and eventually to serve the user public. Two primary areas of concern are long-term stability data and an automatic user alert system. The seasonal changes in the minichain grid caused by temperature, ice, snow, fog, and rain must be carefully measured to verify that the required accuracy can be maintained in all types of weather. An automatic user alert, or blink, standard on all other Loran chains, should be included in the minichain to warn the user when the chain is out of tolerance.

8.3 WAY POINT MEASUREMENT TECHNIQUE

A better technique for measuring way points in open water is essential. Way points could be measured in ice with great precision, but in open water, with current, wind, and heavy traffic, the measurements were marginal at best. The procedure might involve a dynamic or on-the-fly measurement with post-mission position and TD determination. Another approach might involve measuring TD's at several fixed points near the way point and mathematically interpolating to the way point.

8.4 WAY POINT DATA STANDARDIZATION

Before the Coast Guard disseminates the measured TD's to the user public, it is essential to determine through carefully controlled tests if significant errors will result in using these TD's on other types of boats and with other types of shipboard equipment. Should the errors prove to be significant, it will be necessary to devise ways to calibrate boats and to apply these corrections automatically in the shipboard equipment. It does not appear to be practical to require each boat, especially a 1000-ft boat, to measure empirically its own TD's for each way point.

8.5 LOCAL GRID DISTORTIONS

Further studies should be made of the local grid distortions observed. Several areas with local distortion have been observed. Correction techniques might include relocating transmitting stations or modifying the transformation algorithms used in the shipboard equipment.

8.6 USER PUBLIC INVOLVEMENT

Greater effort should be made to involve and solicit feedback from the people who will ultimately use the shipboard minichain equipment on the St. Marys River.

8.7 MINICHAIN EQUIPMENT EVALUATION

A plan for an orderly and efficient evaluation of minichain equipment for the St. Marys River should be developed. The minichain has the potential for use in search and rescue, automatic vessel reporting, and collision avoidance. The potential also exists to use the equipment throughout all of the Great Lakes and off the east coast with other Loran chains. All of these features are technically feasible and relatively inexpensive, considering the large number of potential users.

8.8 TECHNICAL DATA DISSEMINATION

To encourage and accommodate commercial development of navigation systems for the St. Marys River, a data package should be prepared containing: results of the St. Marys River tests, suggested systems configurations, and any expected government performance requirements. Documentation on hardware, software, and transformation algorithms for systems previously developed by APL and others should be referenced in the data package.

Appendix A

SOFTWARE PROGRAM LISTINGS

This appendix contains the software listings for the navigation program and a memory map of the extended memory showing the organization of software in the memory for the navigation program. Following these are the software listings for the position jitter program (as modified from the navigation program), the COGLAD statistical program, the way point library handler program, the simulation program, and the track plot program.

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LAUREL, MARYLAND

[90-99]

Title EXECUTIVE PROGRAM #00 1/24/75 G.E. BAER

Step	Key	Code	Display x	Display y	Display z
0 0	↑	27			
1	1				
2	1				
3	FMT	42			
4	GOTO	44			
5	2				
6	1				
7	FMT	42			
8	GOTO	44			
9	2				
a	2				
b	FMT	42			
c	GOTO	44			
d	3				
1 0	1				
1	FMT	42			
2	GOTO	44			
3	4				
4	1				
5	FMT	42			
6	GO TO	44			
7	e	12			
8	FMT	42			
9	⇑	52			
a	↑	27			
b	2				
c	3				
d	1				
2 0	FMT	42			
1	y→()	40			
2	÷	15			
3	FMT	42			
4	⇑	52			
5	↑	27			
6	2				
7	3				
8	2				
9	FMT	42			
a	y→()	40			
b	FMT	42			
c	ACC-	63	TDC	TCB	
d	PRINT	45			

Step	Key	Code	Display x	Display y	Display z
3 0	↑	27			
1	4				
2	1				
3	FMT	42			
4	GOTO	44			
5	5				
6	1				
7	FMT	42			
8	GO TO	44			
9	IF FLAG	42			
a	2				
b	b	14			
c	6				
d	1				
4 0	FMT	42			
1	GOTO	44			
2	7				
3	1				
4	FMT	42			
5	GOTO	44			
6	x←()	67			
7	−	34			
8	4		ATD		
9	↑				
a	x←()	67			
b	−	34			
c	7		ATS	ATD	
d	÷	35			
5 0	6				
1	0				
2	X			Time	(mins)
3	2				
4	4				
5	6				
6	FMT	42			
7	y→()	40	246	Time	
8	8				
9	1				
a	FMT	42			
b	GOTO	44			
c	CLEAR	20			
d	x←()	67			

Step	Key	Code	Display x	Display y	Display z
6 0	−	34			
1	4		ATD	0	
2	IF x>y				
3	2				
4	b	14			
5	2				
6	4				
7	4				
8	FMT	42			
9	⇑	52	WP		
a	↑	27			
b	1		1	WP	
c	+	33		WP+1	
d	2				
7 0	4				
1	4				
2	FMT	42			
3	y→()	40	244	WP+1	
4	2				
5	2				
6	2				
7	FMT	42			
8	⇑	52	YLP		
9	↑	27			
a	1				
b	5				
c	0				
d	0		100	YLP	

Storage

	+	−
f		
e		
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c		
b		
a		
9		
8		
7		
6		
5		CTE
4		ATD
3		
2		
1		
0		

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 [90-99]

Title Executive #00 1/24/75 G. E. Baer

Step		Key	Code	Display x	Display y	Display z
8	0	-	34			
	1	4				
	2	CHGSGN	32			
	3	ENTEXP	26			
	4	3		4000	YLP	
	5	IFX<Y	52			
	6	8				
	7	a	13			
	8	0				
	9	↑				
	a	2				
	b	z				
	c	2				
	d	FMT	42			
9	0	y→( )	40	222	YLP	
	1	CLEAR X	37			
	2	FMT	42			
	3	↑	27			
	4	GO TO	44			
	5	0				
	6	d	17			
	7	FMT	42			
	8	END	46			
	9					
	a					
	b					
	c					
	d					
	0					
	1					
	2					
	3					
	4					
	5					
	6					
	7					
	8					
	9					
	a					
	b					
	c					
	d					

Step	Key	Code	Display x	Display y	Display z
0					
1					
2					
3					
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5					
6					
7					
8					
9					
a					
b					
c					
d					
0					
1					
2					
3					
4					
5					
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8					
9					
a					
b					
c					
d					
0					
1					
2					
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5					
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7					
8					
9					
a					
b					
c					
d					

Step	Key	Code	Display x	Display y	Display z
0					
1					
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3					
4					
5					
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7					
8					
9					
a					
b					
c					
d					
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6					
7					
8					
9					
a					
b					
c					
d					

Storage	
f	
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b	
a	
9	
8	
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6	
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4	
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2	
1	
0	

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[0-7]

Title SUB IASSID PROGRAM #11 1/25/75 G.E. BAER

Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z
00	2			WP		30	ACC-	63				60	+	33			
1	4					1	↑	27				1	y⇄()	24			
2	4					2	ENTEXP	26				2	C	16			
3	FMT	42	244	WP		3	3					3	↓	25			
4	y→()	40				4	CHG SGN	32				4	↓	25			
5	FMT	42	MASTER			5	X	36				5	ACC-	63			
6	3		RESET			6	ROLL ↑	22				6	GOTO	44			
7	CLEAR	20				7	X	36				7	4				
8	2					8	↓	25				8	3				
9	2					9	X⇄Y	30				9	↑	27			
a	2					a	ACC+	60				a	2				
b	FMT	42				b	1					b	2				
c	y→()	40	220	0		c	1					c	9	11			
d	2					d	ENTEXP	26				d	FMT	42			
10	3					40	4					70	y→()	40			
1	9					1	↑	27				1	↓	25			
2	FMT	42				2	ACC	60				2	2				
3	y→()	40	239	0		3	÷	15				3	3				
4	2					4	IF X>Y	53	TBA 11000			4	0				
5	4					5	SUB	77				5	FMT	42			
6	0					6	5					6	y→()	40			
7	FMT	42				7	5					7	FMT	42			
8	y→()	40	240	0		8	e	12				8	END	46			
9	2					9	IF X>Y	53	TCE 11500			9					
a	4					a	5					a					
b	1					b	9	11				b					
c	FMT	42				c	b	14				c					
d	y→()	40	241	0		d	↑	27				d					
20	2					50	a	13									
1	4					1	IF X<Y	52									
2	2					2	6										
3	FMT	42				3	9	11									
4	y→()	40	242	0		4	STOP	41									
5	2					5	C	16									
6	4					6	X→()	23									
7	3					7	a	13									
8	FMT	42				8	SUB/RTN	77									
9	y→()	40	243	0		9	C	16									
a	CLEAR	20				a	X→()										
b	X→()	23				b	b	14									
c	C	16				c	↑	27									
d	FMT					d	1										

Storage

f	
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a	
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5	
4	
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2	
1	
0	

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[8-17] G.E. BAER

Title COMPUTING OF A, B, C, D, E', & F' PROGRAM No. 21 10/24/75

Step	Key	Code	Display x	Display y	Display z
00	CLR	20			
1	1				
2	0				
3	0				
4	FMT	42			
5	⇈	56	X_m		
6	↑	27			
7	X	36			
8	↑	27			
9	2				
a	2				
b	6				
c	FMT	42	226	X_m	X_m^2
d	y→()	40			
10	x→()	23			
1	d	17			
2	2				
3	2				
4	5				
5	FMT	42	225		
6	y→()	40			
7	x→()	23			
8	c	16			
9	↓	25		X_m^2	
a	2				
b	3				
c	1	11			
d	FMT	42	229		
20	y→()	40			
1	1				
2	0				
3	1				
4	FMT	42			
5	⇈	56	Y_m		
6	↑	27			
7	X	36			
8	↑	27			
9	2				
a	2				
b	3				
c	FMT	42	223	X_m	X_m^2
d	y→()	40			

Step	Key	Code	Display x	Display y	Display z
30	x→()	23			
1	a	13			
2	2				
3	2				
4	4				
5	FMT	42	224		
6	y→()	40			
7	x→()	23			
8	b	14			
9	↓	25		Y_m^2	
a	2				
b	3				
c	1				
d	FMT	42			
40	+	33			
1	2				
2	3				
3	0				
4	FMT	42			
5	⇈	56	TO B offset		
6	↑	27			
7	1				
8	−	34			
9	3				
a	X	36			
b	1				
c	0				
d	2				
50	+	33		[illegible]	
1	y→()	40			
2	f	15			
3	2				
4	2				
5	9				
6	FMT	42	TO A offset		
7	⇈	56			
8	↑	27			
9	1				
a	−	34			
b	3				
c	X	36			
d	1				

Step	Key	Code	Display x	Display y	Display z
60	0				
1	2				
2	+	33		X_A address	
3	y→()	40			
4	e	12			
5	↓	25			
6	FMT	42			
7	⇈	56	X_A		
8	↑	27			
9	X	36	X_A	X_A^2	
a	↑	27			
b	c	16			
c	FMT	42	225	X_A	X_A^2
d	−	34			
70	↓	25			
1	2				
2	2				
3	7				
4	FMT	42			
5	y→()	40		X_A^2	
6	f	15			
7	FMT	42			
8	⇈	56	X_B		
9	↑	27			
a	X	36			
b	↑	27		X_A	X_A^2
c	d	17			
d	FMT	42			

Storage

Reg.	Contents
f	ADDRESS OF [illegible]
e	ADDRESS OF [illegible]
d	226
c	225
b	224
a	223
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

AD-A037 315 JOHNS HOPKINS UNIV LAUREL MD APPLIED PHYSICS LAB F/G 17/7
SAINT MARYS RIVER COGLAD NAVIGATION SYSTEM.(U)
FEB 77 C R EDWARDS, R C MOORE, G E BAER N00017-72-C-4401
UNCLASSIFIED APL/JHU-CP-053 NL

2 OF 2
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END
DATE
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APPLIED PHYSICS LABORATORY
LAUREL, MARYLAND

BEST AVAILABLE COPY

[8-17]

Title #21 PROGRAM #21 10/27/75 G. E. ZAER

Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z
8 0	−	34				0						0					
1	↓	25				1						1					
2	2					2						2					
3	2					3						3					
4	8					4						4					
5	FMT	42				5						5					
6	y→()	40				6						6					
7	1					7						7					
8	↑	27				8						8					
9	ACC +	60				9						9					
a	e	12				a						a					
b	FMT	42				b						b					
c	⇑	36	Y_A			c						c					
d	↑	27				d						d					
9 0	X	36				0						0					
1	↑	27				1						1					
2	a	13				2						2					
3	FMT	42				3						3					
4	−	34				4						4					
5	↓	25				5						5					
6	2					6						6					
7	2					7						7					
8	7					8						8					
9	FMT	42				9						9					
a	+	33				a						a					
b	FMT	42				b						b					
c	END	46				c						c					
d						d						d					

Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z
0						0					
1						1					
2						2					
3						3					
4						4					
5						5					
6						6					
7						7					
8						8					
9						9					
a						a					
b						b					
c						c					
d						d					

Storage	
f	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

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[13 - 23]

Title COMPUTING A', B', C', D, E', F'   PROGRAM # 22   10/27/75 G.E. BREE.

Step	Key	Code	Display x	Display y	Display z
00	+	15	Y_B		
1	FMT	42			
2	⇈	56			
3	↑	27			
4	x	36			
5	↑	27			
6	b	14			
7	FMT	42			
8	−	34			
9	↓	25			
a	2				
b	2				
c	8				
d	FMT	42			
10	+	33			
1	2				
2	3				
3	1				
4	FMT	42			
5	⇈	56	R_m^2		
6	↑	27			
7	2				
8	2				
9	8				
a	FMT	42			
b	−	34			
c	2				
d	2				
20	7				
1	FMT	42			
2	−	34			
3	a	13			
4	FMT	42			
5	⇈	56			
6	↑	27		A	
7	d	17			
8	FMT	42			
9	⇈	56	D		
a	x	36		AD	
b	b	14			
c	FMT	42			
d	⇈	56			

Step	Key	Code	Display x	Display y	Display z
30	↑	27			
1	c	16			
2	FMT	42			
3	⇈	56			
4	x	36		BC	AD
5	↓	25			
6	−	34		Δ	
7	a	13			
8	FMT	42			
9	÷	35			
a	b	14			
b	FMT	42			
c	÷	35			
d	c	16			
40	FMT	42			
1	÷	35			
2	d	17			
3	FMT	42			
4	÷	35			
5	1				
6	↑	27			
7	ACC +	60			
8	e	12			
9	x → ( )	23			
a	−	34			
b	0				
c	+	15			
d	x → ( )	23			
50	−				
1	/				
2	FMT	42			
3	END	46			
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					

Storage

[24-28]

Title SUB WPLUP PROGRAM #31 2/10/76 G.E. BAER

Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z
00	CLEAR	20				30	3					0					
1	2					1	0					1					
2	4					2	FMT	42				2					
3	4					3	⇑	56				3					
4	FMT	42				4	+	33				4					
5	⇑	56				5	↓	25				5					
6	↑	27				6	FMT	42				6					
7	3					7	⇑	56				7					
8	0					8	↑	27				8					
9	IFX>Y		30	WP		9	F	15				9					
a	1					a	↑	27				a					
b	2					b	2					b					
c	−	34				c	2					c					
d	GO TO	44				d	9	11				d					
10	0					40	FMT	42				0					
1	9	11				1	⇑	56				1					
2	1					2	+	33				2					
3	−	34				3	↓	25				3					
4	4					4	FMT	42				4					
5	X	36				5	⇑	56				5					
6	1		FIRST			6	↑	27				6					
7	1		ADDRESS IN			7	FMT	42				7					
8	8		W.P. LIBRARY			8	END	46				8					
9	+	33				9						9					
a	1					a						a					
b	−	34				b						b					
c	y→()	40				c						c					
d	F	15				d						d					
20	4					0											
1	+	33				1											
2	↓	25				2											
3	FMT	42				3											
4	⇑	56	θD			4											
5	↑	27				5											
6	2					6											
7	4					7											
8	5					8											
9	FMT	42				9											
a	y→()	40	245	θD		a											
b	F	15				b											
c	↑	27				c											
d	2					d											

Storage

F	118 + 4(WP-1) = ADDRESS
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

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[29-35]

Title Computing μ_A, μ_B, E & F Program #41 10/31/75 G.E. Pi[illegible]

Step	Key	Code	Display x	Display y	Display z
0	2			TDA	TDB
1	3				
2	3				
3	x→( )	23			
4	a	13			
5	FMT	42			
6	y→( )	40	233	TDA	
7	↓	25			
8	2				
9	3				
a	4				
b	x→( )	23			
c	b	14			
d	FMT	42	234	TDS	
0	y→( )	40			
1	x←( )	67			
2	−	34			
3	0				
4	FMT	42			
5	⤒	56	n:lk		
6	↑	27			
7	a	13			
8	FMT	42			
9	−	34			
a	x←( )	67			
b	−	34			
c	1				
d	FMT	42			
0	⤒	56	AEDB		
1	↑	27			
2	b	14			
3	FMT	42			
4	−	34			
5	1				
6	1				
7	1				
8	FMT	42			
9	⤒	56	V_p		
a	↑	27			
b	a	13			
c	FMT	42			
d	X	36			

Step	Key	Code	Display x	Display y	Display z
0	b	14			
1	FMT	42			
2	X	36			
3	FMT	42			
4	⤒	56			
5	↑	27			
6	X	36		μ_B^2	
7	2				
8	5				
9	8	10			
a	x→( )	23			
b	÷	15			
c	FMT	42			
d	y→( )	40			
0	a	13			
1	FMT	42			
2	⤒	56			
3	↑	27			
4	X	36		μ_A^2	
5	2				
6	3				
7	7				
8	x→( )	23			
9	e	12			
a	FMT	42			
b	y→( )	40			
c	e	12			
d	2				
0	2				
1	7				
2	FMT	42			
3	⤒	56	E^1		
4	↑	27			
5	e	12			
6	FMT	42			
7	−	34			
8	2				
9	2				
a	8	10			
b	FMT	42			
c	⤒	56			
d	↑	27			

Step	Key	Code	Display x	Display y	Display z
0	÷	15			
1	FMT	42			
2	−	34			
3	4				
4	2				
5	FMT	42			
6	GOTO	44			
7	4				
8	3				
9	FMT	42			
a	GOTO	44			
b	FMT	42			
c	END	46			
d					
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					

Storage

f	238
e	237
d	
c	
b	234
a	233
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

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10/27/75 G.E. BAER [36-44]

Title Computing $\beta, \delta, \alpha, \xi\ \gamma$ PROGRAM # 42 (86)

Step	Key	Code	Display x	Display y	Display z
00	2				
1	2				
2	6				
3	FMT	42			
4	↑↑	56	D'		
5	↑	27			
6	2				
7	3				
8	5				
9	x→( )	23			
a	c	16			
b	FMT	42			
c	y→( )	40			
d	2				
10	3				
1	6				
2	x→( )	23			
3	d	17			
4	FMT	42			
5	y→( )	40			
6	a	13			
7	FMT	42			
8	↑↑	56	μ_A		
9	↑	27			
a	c	16	240	μ_A	
b	FMT	42			
c	×	36			
d	e	12			
20	FMT	42			
1	↑↑	56	E		
2	↑	27			
3	d	17	241	E	
4	FMT	42			
5	×	36			
6	2				
7	2				
8	5				
9	FMT	42			
a	↑↑	56	C'		
b	↑	27			
c	↑	27			
d	b	14			

Step	Key	Code	Display x	Display y	Display z
30	FMT	42			
1	↑↑	56	μ_B	C'	C'
2	×	36		$C'\mu_B$	
3	c	16			
4	FMT	42			
5	−	34			
6	↓	25			
7	F	15			
8	FMT	42			
9	↑↑	56			
a	×	36			
b	d	17			
c	FMT	42			
d	−	34			
40	a	13			
1	FMT	42			
2	↑↑	56			
3	↑	27		μ_A	
4	d	17			
5	FMT	42			
6	↑↑	56	α		
7	↑	27			
8	a	13			
9	FMT	42			
a	y→( )	40			μ_A
b	↓	25		μ_A	
c	2				
d	2				
50	4				
1	FMT	42			
2	↑↑	56	B'		
3	×	36	B'	$B'\mu_A$	μ_A
4	x⇄y	30			
5	CHG. SGN	32			
6	↑	27		$-B'\mu_A$	B'
7	d	17			
8	FMT	42			
9	y→( )	40			
a	↓	25		B'	
b	e	12			
c	FMT	42			
d	↑↑	56	E		

Step	Key	Code	Display x	Display y	Display z
60	×	36		EB'	
1	b	14			
2	FMT	42			
3	↑↑	56	μ_B		
4	x⇄y	30			
5	CHG SGN	32	−FB'	μ_B	
6	↑	27			
7	b	14			
8	FMT	42			
9	y→( )	40	239	−EB'	μ_B
a	↓	25			
b	2				
c	2				
d	3				
70	FMT	42			
1	↑↑	56	A'	μ_B	
2	×	36	A'	$A'\mu_B$	
3	x⇄y	30			
4	↑	27			
5	d	17	241		
6	FMT	42			
7	+	33	241	$A'\mu_B$	A'
8	↓	25		A'	
9	F	15			
a	FMT	42			
b	↑↑	56	F	A'	
c	×	36		FA'	
d	b	14			

Storage

f	238 F
e	237 E
d	236 · α - δ
c	235 - β
b	234 · μ_B - γ
a	233 · μ_A - α
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

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[36-44]

Title PROGRAM #2 10/27/75

Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z
8 0	FMT	42				0						0					
1	+	33				1						1					
2	z					2						2					
3	↑	27				3						3					
4	a	13				4						4					
5	FMT	42				5						5					
6	÷	35				6						6					
7	b	14				7						7					
8	FMT	42				8						8					
9	÷	35				9						9					
a	FMT	42				a						a					
b	END	46				b						b					
c						c						c					
d						d						d					

Storage

Register	
f	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

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[45-53]

Title Computing ξ, ξ', η, θ_m, X & Y Program #43 (07) 10/7/75 R.E.B.

Step	Key	Code	Display x	Display y	Display z
00	a	13			
1	FMT	42			
2	⇑	56	α		
3	↑	27			
4	1				
5	0				
6	1				
7	FMT	42			
8	⇑	56	Y_m	α	
9	−	34		$\alpha - Y_m$	
a	F	15	238		
b	FMT	42			
c	y→( )	40			
d	↓	25			
10	↑	27			
1	×	36		$(\ )^2$	
2	e	12	237		
3	FMT	42			
4	y→( )	40			
5	c	16	235		
6	FMT	42			
7	⇑	56	β		
8	↑	27			
9	F	15	238		
a	FMT	42			
b	×	36			
c	b	14			
d	FMT	42			
20	⇑	56	γ		
1	↑	27			
2	1				
3	0				
4	0				
5	FMT	42			
6	⇑	56	X_m	γ	
7	−	34		$(\gamma - X_m)$	
8	↓	25			
9	↑	27			
a	×	36	$(\ )$	$(\ )^2$	
b	↑	27			
c	d	17	236		
d	FMT	42			

Step	Key	Code	Display x	Display y	Display z
30	⇑	56	δ		
1	×	36		$\delta(\ )$	$(\ )^2$
2	F	15	238		
3	FMT	42			
4	+	33			
5	↓	25			
6	e	12	237		
7	FMT	42			
8	+	33		$(\ )^2$	
9	c	16			
a	FMT	42			
b	⇑	56	β		
c	↑	27	β	β	
d	×	36		β^2	
40	d	17			
1	FMT	42			
2	⇑	56	δ		
3	↑	27	δ	δ	
4	×	36		δ^2	
5	1.				
6	−	34			
7	↓	25			
8	+	33		η	
9	e	12			
a	FMT	42			
b	⇑	56	ξ		
c	×	36		$\xi\eta$	
d	F	15			
50	FMT	42			
1	⇑	56	ξ'		
2	↑	27	ξ'	ξ'	$\xi\eta$
3	×	36	ξ'	ξ'^2	$\xi\eta$
4	CHG SGN	32	$-\xi'$		
5	ROLL↓	31	ξ'^2	$\xi\eta$	$-\xi'$
6	−	34			
7	↓	25			
8					
9	$\sqrt{x}$	76			
a	+	36			
b	e	12			
c	FMT	42			
d	⇑	56	ξ		

Step	Key	Code	Display x	Display y	Display z
60	x⇄y	30			
1	÷	35		θ_m	
2	e	12			
3	FMT	42			
4	y→( )	40			
5	F	15			
6	FMT	42			
7	y→( )	40			
8	c	16			
9	FMT	42			
a	⇑	56			
b	↑	27			
c	F	15			
d	FMT	42			
70	×	36			
1	a	13			
2	FMT	42			
3	⇑	56			
4	↑	27			
5	F	15			
6	FMT	42			
7	+	33			
8	d	17			
9	FMT	42			
a	⇑	56			
b	↑	27			
c	e	12			
d	FMT	42			

Storage

Register	Contents
f	238
e	237
d	236
c	235
b	234
a	233
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

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Title $\xi, \xi', \eta, \theta_M, X, \xi\ Y$ PROGRAM #43

Step	Key	Code	Display x	Display y	Display z
3 0	X	30			
1	b	14			
2	FMT	42			
3	↑	56	γ		
4	↑	27			
5	e	12			
6	FMT	42			
7	+	33			
8	FMT	42			
9	END	46			
a					
b					
c					
d					

Storage

f	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

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[54-58]

Title SUB XYDR PROGRAM #51 10/27/75 G.E. BKER

Step	Key	Code	Display x	y	z	Step	Key	Code	Display x	y	z	Step	Key	Code	Display x	y	z
00	CLEAR	20				30	4					0					
1	2					1	b	14				1					
2	3					2	2					2					
3	9					3	3					3					
4	FMT	42				4	7					4					
5	⇑	56				5	FMT	42				5					
6	IF x>y	50				6	⇑	56				6					
7	3					7	↑	27				7					
8	2					8	2					8					
9	↑	27				9	3					9					
a	2					a	9	11				a					
b	4					b	FMT	42				b					
c	1					c	y→()	40				c					
d	FMT	42				d	2					d					
10	⇑	56				40	3					0					
1	↑	27				1	8	10				1					
2	1					2	FMT	42				2					
3	1					3	⇑	56				3					
4	2					4	↑	27				4					
5	FMT	42				5	2					5					
6	⇑	56				6	4					6					
7	X	36				7	0					7					
8	Roll ↓	31				8	FMT	42				8					
9	+	33				9	y→()	40				9					
a	y→()	40				a	Set Flag	54				a					
b	≠	15				b	FMT	42				b					
c	↓	25				c	END	46				c					
d	2					d						d					
20	4					0											
1	2					1											
2	FMT	42				2											
3	⇑	56				3											
4	X	36				4											
5	2					5											
6	4					6											
7	0					7											
8	FMT	42				8											
9	⇑	56				9											
a	+	33				a											
b	y→()	40				b											
c	e	12				c											
d	GOTO	44				d											

Storage

f	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

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11/17/75 [59 - 63]

Title SUB TSTPP PROGRAM #61 10/27/75 G.E. BAER

Step	Key	Code	Display x	Display y	Display z
0 0	e	12			
1	↑	27			
2	2				
3	3				
4	8	10			
5	FMT	42			
6	↑↑	56			
7	−	34			
8	|Y|	55		|ΔY|	
9	÷	15			
a	↑	27			
b	2				
c	3				
d	7				
1 0	FMT	42			
1	↑↑	56			
2	−	34			
3	|Y|	55		|ΔX|	|ΔY|
4	1				
5	1				
6	3				
7	FMT	42			
8	↑↑	56	K_2	|ΔX|	
9	IFX<Y	52			
a	3				
b	0				
c	↓	25			
d	7				
2 0	1				
1	3				
2	FMT	42			
3	↑↑	56			
4	IFX<Y	52	K_3	|ΔY|	
5	3				
6	0				
7	6				
8	2				
9	FMT	42			
a	GOTO	44			
b	GOTO	44			
c	4				
d	a				

Step	Key	Code	Display x	Display y	Display z
3 0	FMT	42			
1	3				
2	÷	15			
3	↑	27			
4	2				
5	3				
6	9	11			
7	FMT	42			
8	y→()	40			
9	e	12			
a	↑	27			
b	2				
c	4				
d	0				
4 0	FMT	42			
1	y→()	40			
2	CLEAR	20			
3	FMT	42			
4	IFX>Y	53			
5	2				
6	4				
7	3				
8	FMT	42			
9	y→()	40			
a	FMT	42			
b	END	46			
c					
d					
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					

Storage

Register	Contents
f	X_{OR}
e	Y_{OR}
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

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[64-71]

Title #62 SUB PPDATA 11/13/75 G.E. BAER

Step	Key	Code	Display x	Display y	Display z
0	1				
1	↑	27			
2	1				
3	1				
4	6				
5	FMT	42			
6	⇑	56	K5	1	
7	−	34	K5	1-K5	
8	X→( )	23			
9	e	12			
a	2				
b	4				
c	1				
d	FMT	42			
0	X	36	241	1-K5	
1	2				
2	4				
3	2				
4	FMT	42			
5	X	36	242	1-K5	
6	2				
7	3				
8	9	11			
9	FMT	42			
a	⇑	56	X_{n-1}		
b	CHG SGN	32	$-X_{n-1}$		
c	↑	27			
d	2				
0	3				
1	7				
2	FMT	42			
3	⇑	56	X_{pp}	$-X_{n-1}$	
4	+	33			
5	↑	27			
6	2				
7	3				
8	9	11			
9	FMT	42	239	X_{pp}	ΔX
a	Y→( )	40			
b	↓	25			
c	e	12			
d	X	36		K5ΔX	

Step	Key	Code	Display x	Display y	Display z
0	Y→( )	40			
1	F	15			
2	2				
3	4				
4	3				
5	FMT	42			
6	⇑	56	T_{n-1}		
7	CHG SGN	32			
8	ROLL↓	31			$-T_{n-1}$
9	FMT	42			
a	COS X	73			
b	X⇄Y	30		T	
c	1				
d	1				
0	5				
1	FMT	42			
2	⇑	56			
3	X	36			
4	2				
5	4				
6	3				
7	FMT	42			
8	Y→( )	40			
9	↓	25			
a	+	33		ΔT	
b	F	15			
c	X⇄Y	30	ΔT	K5ΔX	
d	÷	35			
0	X→( )	23			
1	F	15			
2	2				
3	4				
4	1				
5	FMT	42			
6	+	33	241	K5ΔX	
7	2				
8	4				
9	0				
a	FMT	42			
b	⇑	56	Y_{n-1}		
c	CHG SGN	32	$-Y_{n-1}$		
d	↑	27			

Step	Key	Code	Display x	Display y	Display z
0	2				
1	3				
2	8				
3	FMT	42			
4	⇑	56			
5	+	33	Y_{pp}	ΔY	
6	↑	27			
7	2				
8	4				
9	0				
a	FMT	42			
b	Y→( )	40			
c	↓	25			
d	e	12			
0	X	36			
1	F	15			
2	÷	35			
3	2				
4	4				
5	2				
6	FMT	42			
7	+	33			
8	FMT	42			
9	END	46			
a					
b					
c					
d					

Storage

Register	Contents
f	K5ΔX } ΔT
e	K5
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

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[72-77]

Title SUB ATCT PROGRAM #71 4/4/76 G. E. BAER

Step	Key	Code	Display x	Display y	Display z
00	2				
1	3				
2	2				
3	FMT	42			
4	⇈	56	Y_0		
5	↑	27			
6	2				
7	4				
8	0				
9	FMT	42			
a	⇈	56	Y	Y_0	
b	−	34		ΔY	
c	2				
d	4				
10	2				
1	FMT	42			
2	⇈	56	V_{yn}	ΔY	
3	↑	27			
4	1				
5	1				
6	4				
7	FMT	42			
8	⇈	56	K	V_y	ΔY
9	X	36			
a	ROLL↓	31			
b	−	34			
c	2				
d	4				
20	1				
1	FMT	42			
2	⇈	56	V_{yn}	$ΔY_L$	K
3	ROLL↑	22			
4	CHG SGN	32			
5	×	36			
6	2				
7	3				
8	1				
9	FMT	42			
a	⇈	56	XD	KV_{yn}	$ΔY_L$
b	+	33			
c	2				
d	3				
30	9				
1	FMT	42			
2	⇈	56	X		
3	−	34		$ΔX_L$	$ΔY_L$
4	7				
5	2				
6	FMT	42			
7	GO TO	44		CTE	ATD
8	↓	25			
9	CHG SGN	32			
a	X⇄Y	30	ATD	CTE	
b	↑				
c	7				
d	3				
40	FMT	42			
1	GO TO	44			
2	2				
3	4				
4	2				
5	FMT	42			
6	⇈	56	V_Y		
7	↑	27			
8	2				
9	4				
a	1				
b	FMT	42			
c	⇈	56	V_X	V_Y	
d	↑	27			
50	7				
1	2				
2	FMT	42			
3	GO TO	44			
4	↓	25			
5	X⇄Y	30			
6	↑				
7	7				
8	4				
9	FMT	42			
a	GO TO	41			
b	FMT	42			
c	END	46			
d					

Storage

Register	Contents
F	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

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[78-79]

Title SUB AROT PROGRAM #72 11/17/75 G.E. BAER

Step	Key	Code	Display x	Display y	Display z
00	↓	25	X	Y	
1	X⇄Y	30	Y	X	
2	To Polar	62	R	θ	
3	X⇄Y	30	θ	R	
4	↑	27			
5	2				
6	4				
7	5				
8	FMT	42			
9	↑	52	θ_0	θ	R
a	−	34			
b	↓	25			
c	X⇄Y	30	R	$\theta-\theta_0$	
d	To Rect	66	X	Y	
10	↑	27			
1	1				
2	.	21			
3	7				
4	6				
5	÷	35			
6	3				
7	ENT EXP	26			
8	3				
9	Roll ↑	22			
a	X	36		Y	X
b	FMT	42			
c	END	46		Y	X
d					

Storage

f	
e	
d	
c	
b	
a	
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1	
0	

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[80-86]

Title SUB DATCT PROGRAM #73 2/10/76 G. E. BAER

Step	Key	Code	Display X	Display Y	Display Z
0 0	↓	25			
1	PRINT	45	ATD CTE		
2	X→()	23			
3	−	34			
4	4				
5	Y→()	40			
6	−	34			
7	5				
8	FMT	42		DIGITAL	
9	X→()	23	ATD	DISPLAY ATD	
a	↑	27			
b	2				
c	4				
d	7				
1 0	FMT	42			
1	Y→()	40			
2	.	21			
3	0				
4	4		.04 ATD		
5	÷	35			
6	4				
7	0				
8	0		400	ATD/.04	
9	+	33		ATD/.04 +400	
a	↓	25	AATD		
b	INT x	64			
c	FMT	42		ANALOG	
d	d	17	ATD	DISPLAY ATD	
2 0	↓	25			
1	FMT	42		DIGITAL	
2	7		CTE	DISPLAY CTE	
3	↑	27			
4	2				
5	0				
6	0				
7	IFX<Y	52	200 CTE		
8	3				
9	0				
a	CHG SGN	32			
b	IFX<Y	52	-200 CTE		
c	3				
d	8	10			

Step	Key	Code	Display X	Display Y	Display Z
3 0	.	21			
1	1		.1	CTE	
2	X	36			
3	1				
4	CHG SGN	32	-1		
5	GO TO				
6	3				
7	9	11			
8	.1				
9	X→()	23			
a	e	12			
b	2		2	CTE	
c	÷	35			
d	5				
0	0				
1	0		500	CTE/2	
2	+	33			
3	e	12			
4	X	36			
5	↓	25	ACTE		
6	INT x	64			
7	FMT	42		ANALOG	
8	CLR x	37	CTE	DISPLAY CTE	
9	X←()	67			
a	−	34			
b	5		CTE		
c	↑				
d	0			CTE SCALE	
0	5			100 FT/IN	
1	CHG SGN	32			
2	X	36			
3	2				
4	2				
5	2				
6	FMT	42			
7	↑↑	52	YLP		
8	+				
9	X←()	67			
a	−	34			
b	4		ATD		
c	↑	27			
d	1		7		

Step	Key	Code	Display X	Display Y	Display Z
0	CHG SGN	32	ATD		
1	ENT EXP	26	SCALE		
2	3		.5 MILE/IN		
3	X	36			
4	↓	25			
5	FMT	42			
6	↓	25	ATD	CTE	
7	FMT	42			
8	END	46			
9					
a					
b					
c					
d					
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					

Storage

	+	−
F		
e	±1	
d		
c		
b		
a		
9		
8		
7		
6		
5		CTE
4		ATD
3		
2		
1		
0		

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Title SUB DATCTS PROGRAM #74 4/4/76 G.E. BAER [87-89]

Step	Key	Code	Display x	Display y	Display z
00	|y|	55		ATS	CTS
1	3				
2	6				
3	0				
4	0				
5	X	36			
6	y→()	40			
7	−	34			
8	7				
9	↓	25			
a	PRINT	45			
b	x→()	23			
c	−	34			
d	6				
0	↑	27			
1	.	21			
2	1				
3	÷				
4	4				
5	0				
6	0				
7	+	33			
8	↓	25			
9	FMT	42	} ANALOG		
a	a	13	} ATS		
b	.	21			
c	0				
d	4				
0	÷	35			
1	5				
2	0				
3	0				
4	+	33			
5	↓	25	CTS		
6	FMT	42	} ANALOG		
7	CONT	47	} CTS		
8	FMT	42			
9	END	46			
a					
b					
c					
d					

Storage

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[89]

Title SUB LLHD PROGRAM #81 10/29/75 G.E. [illegible]

Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z
0	FMT	42				0						0					
1	COS X	73				1						1					
2	CLEAR X	37				2						2					
3	2					3						3					
4	4					4						4					
5	4					5						5					
6	+	33				6						6					
7	↓	25				7						7					
8	FMT	42				8						8					
9	↑	56				9						9					
a	FMT	42				a						a					
b	IF X>Y	53				b						b					
c	FMT	42				c						c					
d	END	46				d						d					
0						0						0					
1						1						1					
2						2						2					
3						3						3					
4						4						4					
5						5						5					
6						6						6					
7						7						7					
8						8						8					
9						9						9					
a						a						a					
b						b						b					
c						c						c					
d						d						d					
0						0											
1						1											
2						2											
3						3											
4						4											
5						5											
6						6											
7						7											
8						8											
9						9											
a						a											
b						b											
c						c											
d						d											

Storage

f	
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Title NAVIGATION MODE — Date 2-9-76 — Page 1 of 1
Name G. E. BAER

9101A MEMORY MAP

0		50		100	X_m	150	9	200	
1		51		101	Y_m	151		201	
2	#11	52		102	X_A	152		202	22
3	IASSID	53		103	Y_A	153		203	
4		54		104	AEDA	154	10	204	
5		55	#51	105	X_B	155		205	
6		56	XYDR	106	Y_B	156		206	23
7		57		107	AEDB	157		207	
8		58		108	X_C	158	11	208	
9		59		109	Y_C	159		209	
10	#21	60	#61	110	AEDC	160		210	24
11		61	TSTPP	111	V_P	161		211	
12	SCON-1	62		112	K_1 Dead Reckoning	162	12	212	
13		63		113	K_2 Window	163		213	
14		64		114	K_6 LAG	164		214	25
15		65	#62	115	K_4 .0493	165		215	
16		66		116	K_5 Velocity	166	13	216	
17		67	PPDATA	117	#81	167		217	
18		68		118	1	168		218	26
19	#22	69		119	Way Point	169		219	
20	SCON-2	70		120	Library	170	14	220	
21		71		121		171		221	
22		72		122	2 TDX	172		222	Y_{LP}
23		73	#71	123	TDY	173		223	A'
24		74		124	TDZ	174	15	224	B'
25	#31	75	ATCT	125	Θ_D	175		225	C'
26	WPLUP	76		126	3	176		226	D'
27		77		127		177		227	E'
28		78	#72	128		178	16	228	F'
29		79	AROT	129		179		229	TDA ADDRESS
30	#41	80		130	4	180		230	TDB OFFSET
31		81	#73	131		181		231	X_D
32		82	DATCT	132		182	17	232	Y_D
33		83		133		183		233	M_A α
34		84		134	5	184		234	M_B γ
35		85		135		185		235	β
36		86		136		186	18	236	δ
37	#42	87	#74	137		187		237	E ξ X
38		88	DATCTS	138	6	188		238	F ζ Y
39		89		139		189		239	X_{n-1}
40		90		140		190	19	240	Y_{n-1}
41		91	#00	141		191		241	$V_{X(n-1)}$
42		92	EXECUTIVE	142	7	192		242	$V_{Y(n-1)}$
43		93		143		193		243	$T_{(n-1)}$
44		94		144		194	20	244	WP
45		95		145		195		245	Θ_D
46	#43	96		146	8	196		246	TTWP
47		97		147		197		247	ATD
48		98		148		198	21		
49		99		149		199			

POSITION JITTER PROGRAM

The following pages contain the modified programs that replace their corresponding parts in the navigation program, thereby creating the position jitter program.

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LAUREL, MARYLAND

[90 - 97]

Title POSITION JITTER EXECUTIVE #00 4/4/76 G. E. BAER

Step	Key	Code	Display x	Display y	Display z
00	↑	27		WP	
01	1				
02	1				
03	FMT	42			
04	GO TO	44			
05	2				
06	1				
07	FMT	42			
08	GO TO	44			
09	2				
0a	2				
0b	FMT	42			
0c	GO TO	44			
0d	2				
10	4				
11	4				
12	FMT	42			
13	⇈	56			
14	↑	27			
15	0				
16	IF X<Y	52			
17	2				
18	1				
19	FMT	42			
1a	ACC -	63	TDA TDB		
1b	↑	27			
1c	GO TO	44			
1d	2				
20	5				
21	3				
22	1				
23	FMT	42			
24	GO TO	44			
25	4				
26	1				
27	FMT	42			
28	GO TO	44			
29	e	12			
2a	FMT	42			
2b	⇈	56			
2c	↑	27			
2d	2				
30	3				
31	1				
32	FMT	42			
33	y→( )	40	231	X_D	
34	F	15			
35	FMT	42			
36	⇈	56			
37	↑	27			
38	2				
39	· 3				
3a	2				
3b	FMT	42			
3c	y→( )	40	232	Y_D	
3d	9				
40	0				
41	↑	27			
42	2				
43	4				
44	5				
45	FMT	42			
46	y→( )	40	245	90°	
47	FMT	42			
48	ACC -	63	TDA	TDB	
49	PRINT	45			
4a	↑	27			
4b	4				
4c	1				
4d	FMT	42			
50	GO TO	44			
51	6				
52	2				
53	FMT	42			
54	GO TO	44			
55	7				
56	1				
57	FMT	42			
58	GO TO	44			
59	8	10			
5a	1				
5b	FMT	42			
5c	GO TO	44			
5d	x←( )	67			
60	–				
61	e	12			
62	↑	27			
63	1				
64	–	34			
65	0				
66	y→( )	40			
67	–	34			
68	e	12			
69	IF X<Y	52			
6a	4				
6b	7				
6c	STOP	41			
6d	FMT	42			
70	END	46			
71					
72					
73					
74					
75					
76					
77					
78					
79					
7a					
7b					
7c					
7d					

Storage

F	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
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0	

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[72 - 74]

Title SUB JITTER ATCT PROGRAM #71 4/4/76 G.E. BAER

Step		Key	Code	Display x	Display y	Display z
0	0	2				
	1	3				
	2	2				
	3	FMT	42			
	4	⥣	56	YD		
	5	↑	27			
	6	2				
	7	4				
	8	0				
	9	FMT	42			
	a	⥣	56	Y	YD	
	b	−	34		ΔY	
	c	2				
	d	3				
1	0	1				
	1	FMT	42			
	2	⥣	56	XD	ΔY	
	3	↑	27			
	4	2				
	5	3				
	6	9				
	7	FMT	42			
	8	⥣	56	Y	XD	ΔY
	9	−	34		ΔX	ΔY
	a	7				
	b	2				
	c	FMT	42			
	d	GO TO	44			
2	0	↓			+CTE	ATA
	1	CH. SIN	32			
	2	X ≶ Y	30			
	3	↑	27			
	4	7				
	5	3				
	6	FMT	42			
	7	GO TO	44			
	8	FMT	42			
	9	END	46			
	a					
	b					
	c					
	d					

Storage

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Title SUB JDATCT PROGRAM #73 4/4/76 G.E. BAER [80-86]

Step	Key	Code	Display x	y	z
00	↓	25			
1	PRINT	45	A-D CTE		
2	X→()	23			
3	−	34			
4	4				
5	y→()	40			
6	−	34			
7	5				
8	FMT	42	} DIGITAL		
9	X→()	23	} DISPLAY ATD		
a	↑	27			
b	2				
c	4				
d	7				
10	FMT	42			
1	y→()	40			
2	.				
3	0				
4	4		.04 ATD		
5	÷	35			
6	4				
7	0				
8	0				
9	+	33			
a	↓	25	AATD		
b	INT x	64			
c	FMT	42	} ANALOG		
d	d	17	} DISPLAY ATD		
0	↓	25			
11	FMT	42	} DIGITAL		
2	7		} DISPLAY CTE		
3	↑	27			
4	2				
5	0				
6	0				
7	IFX<Y	52	200 CTE		
8	3				
9	0				
a	CHG SGN	32			
b	IFX<Y	52	-200 CTE		
c	3				
d	8				

Step	Key	Code	Display x	y	z
0	.	21			
1	1		.1	CTE	
2	X				
3	1				
4	CHG SGN	32	-1		
5	GO TO	40			
6	3				
7	9				
8	1				
9	X→()	23			
a	e	12			
b	2		2	CTE	
c	÷	35			
d	5				
0	0				
1	0				
2	+	33			
3	e	12			
4	X	36			
5	↓	25	ACTE		
6	INT x	64			
7	FMT	42	} ANALOG		
8	CLR X	37	} DISPLAY CTE		
9	X←()	67			
a	−	34			
b	5		CTE		
c	↑				
d	2		} CTE SCALE		
0	0		} 20 FT/IN		
1	CHG SGN	32	}		
2	X	36			
3	2				
4	2				
5	2				
6	FMT	42			
7	↑↑	56	YLP		
8	+				
9	X←()				
a	−	34			
b	4				
c	↑	27			
d	1				

Step	Key	Code	Display x	y	z
0	0		}		
1	5		} ATD		
2	6		} SCALE		
3	0		} 20 FT/IN		
4	0		}		
5	CHG SGN	32	}		
6	X	36			
7	↓	25			
8	FMT	42			
9	↓	25			
a	FMT	42			
b	↑	27			
c	FMT	42			
d	END	46			
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					

Storage

	+	
F		
e	I1	
d		
c		
b		
a		
9		
8		
7		
6		
5		CTE
4		ATD
3		
2		
1		
0		

STATISTICAL PROGRAM

The following pages present the software listing of the COGLAD statistical program.

THE JOHNS HOPKINS UNIVERSITY
APPLIED PHYSICS LABORATORY
LAUREL, MARYLAND

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1

Title COGLAD III STATISTICS CRE 2/17/76

Step	Key	Code	Display x	y	z
00	CLEAR	20			
01	X→( )	23			
02	9	11			
03	X→( )	23			
04	c	16			
05	X→( )	23			
06	d	17			
07	GoTo	44			
08	1	01	for fixed ref.	0	for variable ref.
09	2	02		a	
0a	FMT	42			
0b	Acc −	63	TDA TDB		
0c	X→( )	23			
0d	a	13			
10	Y→( )	40			
11	b	14			
12	FMT	42			
13	Acc −	63	TDA TDB		
14	↑	27			
15	a	13	TDA_R	TDA	TDB
16	−	34			
17	b	14	TDB_R		
18	Roll ↑	22			
19	X⇄Y	30			
1a	−	34			
1b	↓	25			
1c	X⇄Y	30			
1d	Acc +	60	ΔTDA ΔTDB		
20	↑	27			
21	X	36			
22	Roll ↓	31	ΔTDA^2	ΔTDB	ΔTDA
23	Y⇄( )	24			
24	d	17			
25	+	33			
26	Y⇄( )	24			
27	d	17		ΔTDB	
28	↓	25			
29	↑	27			
2a	X	36	ΔTDB	ΔTDB^2	ΔTDA
2b	Roll ↓	31	ΔTDB^2	ΔTDA	ΔTDB
2c	Y⇄( )	24			
2d	c	16			

Step	Key	Code	Display x	y	z
30	+	33			
31	Y⇄( )	24			
32	c	16			
33	↓	25	ΔTDA ΔTDB		
34	To Polar	62			
35	↑	27			
36	2	02	200 n sec		
37	•	21			
38	5	05	Vert. scale		
39	0	00			
3a	X	36			
3b	↓	25			
3c	To Rect	66			
3d	↑	27			
40	1	01	2" vert.		
41	ENT EXP	26	offset in plot		
42	3	03			
43	+	33			
44	Y→( )	40			
45	8	10			
46	1	01			
47	X⇄Y	30			
48	X←( )	67			
49	9	11			
4a	+	33			
4b	Y→( )	40			
4c	9	11			
4d	1	01			
50	3	03	2 min/in		
51	•	21	horiz scale		
52	0	00			
53	0	00			
54	X	36			
55	↓	25			
56	FMT	42			
57	↓	25			
58	FMT	42			
59	↑	27			
5a	Y⇄( )	24			
5b	8	10			
5c	FMT	42			
5d	↓	25			

Step	Key	Code	Display x	y	z
60	FMT	42			
61	↑	27			
62	SF FLAG	43			
63	−	34			
64	0	00			
65	0	00			
66	GoTo	44			
67	1	01	for zero Vel.	6	for TDA, TDB velocity
68	2	02		9	
69	a	13	TDA_R		
6a	↑	27			
6b	X←( )	67			
6c	−	34			
6d	a	13	ΔTDA_R		
70	+	33			
71	Y→( )	40			
72	a	13			
73	b	14	TDB_R		
74	↑	27			
75	X←( )	67			
76	−	34			
77	b	14	ΔTDB_R		
78	+	33			
79	Y→( )	40			
7a	b	14			
7b	GoTo	44			
7c	1	01			
7d	2	02			

Storage

	+	−
f	ΣΔA	
e	ΣΔB	
d	$\Sigma(\Delta A)^2$	
c	$\Sigma(\Delta B)^2$	
b	TDB_R	ΔTDB_R
a	TDA_R	ΔTDA_R
9	N samples	
8	$10^3+K(\Delta A)$	
7		
6		
5		
4		
3		
2		
1		
0		

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2

Title COGLAD III STATISTICS   CRE 2/17/76

Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z
00	d	17				30	↓	25				0					
1	↑	27				1	√x	76				1					
2	X←()	67				2	↑	27				2					
3	9	11				3	b	14				3					
4	÷	35				4	Roll ↑	22				4					
5	f	15				5	+	33				5					
6	↑	27				6	↓	25				6					
7	X←()	67				7	X⇄Y	30				7					
8	9	11				8	↑	27				8					
9	÷	35				9	X←()	67				9					
a	↓	25				a	9	11				a					
b	↑	27				b	PRINT	45				b					
c	X	36				c	SPACE	45				c					
d	Roll ↓	31				d	SPACE	45				d					
10	—	34				0	SPACE	45				0					
1	↓	25				1	SPACE	45				1					
2	√x	76				2	SPACE	45				2					
3	↑	27				3	END	46				3					
4	a	13				4						4					
5	Roll ↑	22				5						5					
6	+	33				6						6					
7	↓	25				7						7					
8	X⇄Y	30				8						8					
9	↑	27				9						9					
a	X←()	67				a						a					
b	9	11				b						b					
c	PRINT	45				c						c					
d	c	16				d						d					
20	↑	27				0											
1	X←()	67				1											
2	9	11				2											
3	÷	35				3											
4	e	12				4											
5	↑	27				5											
6	X←()	67				6											
7	9	11				7											
8	÷	35				8											
9	↓	25				9											
a	↑	27				a											
b	X	36				b											
c	Roll ↓	31				c											
d	—	34				d											

Storage

f	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

WAY POINT LIBRARY HANDLER PROGRAMS

The following pages contain the software listings employed for transferring a way point library from the extended memory to magnetic cards and vice versa.

THE JOHNS HOPKINS UNIVERSITY
APPLIED PHYSICS LABORATORY
LAUREL, MARYLAND

Title FROM EXTENDED MEMORY → MAGNETIC CARD 11/18/75 G.E.[illegible]

Step	Key	Code	Display x	Display y	Display z
-00	↑	27	[illegible]	[illegible]	
1	FMT	42			
2	⇑	56			
3	X→()	23			
4	0				
5	1				
6	+	33			
7	↓	25			
8	↑	27			
9	FMT	42			
a	⇑	56			
b	X→()	23			
c	1				
d	1	1			
-10	+	33			
1	↓	25			
2	↑	27			
3	FMT	42			
4	⇑	56			
5	X→()	23			
6	2				
7	1				
8	+	33			
9	↓	25			
a	↑	27			
b	FMT	42			
c	⇑	56			
d	X→()	23			
-20	3				
1	1				
2	+	33			
3	↓	25			
4	↑	27			
5	FMT	42			
6	⇑	56			
7	X→()	23			
8	4				
9	1				
a	+	33			
b	↓	25			
c	↑	27			
d	FMT	42			

Step	Key	Code	Display x	Display y	Display z
-30	⇑	56			
1	X→()	23			
2	5				
3	1				
4	+	33			
5	↓	25			
6	↑	27			
7	FMT	42			
8	⇑	56			
9	X→()	23			
a	6				
b	1				
c	+	33			
d	↓	25			
-40	↑	27			
1	FMT	42			
2	⇑	56			
3	X→()	23			
4	7				
5	1				
6	+	33			
7	↓	25			
8	↑	27			
9	FMT	42			
a	⇑	56			
b	X→()	23			
c	8				
d	1				
-50	+	33			
1	↓	25			
2	↑	27			
3	FMT	42			
4	⇑	56			
5	X→()	23			
6	9				
7	1				
8	+	33			
9	↓	25			
a	↑	27			
b	FMT	42			
c	⇑	56			
d	X→()	23			

Step	Key	Code	Display x	Display y	Display z
-60	a				
1	1				
2	+	33			
3	↓	25			
4	↑	27			
5	FMT	42			
6	⇑	56			
7	X→()	23			
8	b				
9	1				
a	+	33			
b	↓	25			
c	↑	27			
d	FMT	42			
-70	⇑	56			
1	X→()	23			
2	c				
3	1				
4	+	33			
5	↓	25			
6	↑	27			
7	FMT	42			
8	⇑	56			
9	X→()	23			
a	d				
b	STOP				
c	END		[illegible]		
d					

Storage

	+	−
f		
e		
d		
c		
b		
a		
9	W.P.	
8	LIBRARY	
7		
6		
5		PROGRAM
4		
3		
2		
1		
0		

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Title FROM MAGNETIC CARD TO EXTENCED MEMORY 11/20/75 3.57

Step	Key	Code	Display x	Display y	Display z
00	↑	27	[illegible]		
1	X←()	67			
2	0				
3	X⇄Y	30			
4	FMT	42			
5	Y→()	40			
6	↑	27			
7	1				
8	+	33			
9	X←()	67			
a	1				
b	X⇄Y	30			
c	FMT	42			
d	Y→()	40			
10	↑	27			
1	1				
2	+	33			
3	X←()	67			
4	2				
5	X⇄Y	30			
6	FMT	42			
7	Y→()	40			
8	↑	27			
9	1				
a	+	33			
b	X←()	67			
c	3				
d	X⇄Y	30			
20	FMT	42			
1	Y→()	40			
2	↑	27			
3	1				
4	+	33			
5	X←()	67			
6	4				
7	X⇄Y	30			
8	FMT	42			
9	Y→()	40			
a	↑	27			
b	1				
c	+	33			
d	X←()	67			
30	5				
1	X⇄Y	30			
2	FMT	42			
3	Y→()	40			
4	↑	27			
5	1				
6	+	33			
7	X←()	67			
8	6				
9	X⇄Y	30			
a	FMT	42			
b	Y→()	40			
c	↑				
d	1				
40	+	33			
1	X←()	67			
2	7				
3	X⇄Y	30			
4	FMT	42			
5	Y→()	40			
6	↑	27			
7	1				
8	+	33			
9	X←()	67			
a	8				
b	X⇄Y	30			
c	FMT	42			
d	Y→()	40			
50	↑	27			
1	1				
2	+	33			
3	X←()	67			
4	9				
5	X⇄Y	30			
6	FMT	42			
7	Y→()	40			
8	↑	27			
9	1				
a	+	33			
b	X←()	67			
c	a	13			
d	X⇄Y	30			
60	FMT	42			
1	Y→()	40			
2	↑	27			
3	1				
4	+	33			
5	X←()	67			
6	b	14			
7	X⇄Y	30			
8	FMT	42			
9	Y→()	40			
a	↑	27			
b	1				
c	+	33			
d	X←()	67			
70	c	15			
1	X⇄Y	30			
2	FMT	42			
3	Y→()	40			
4	↑	27			
5	1				
6	+	33			
7	X←()	67			
8	d				
9	FMT	42			
a	Y→()	40			
b	CONT	46			
c	STOP				
d	END				

Storage

f	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

SIMULATION PROGRAM

The following pages present the software listings of programs employed for system checkout via simulation of TD's. Programs are also listed that replace the bridge display as interfaced with the software.

THE JOHNS HOPKINS UNIVERSITY
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LAUREL, MARYLAND

#4 [200-202]   #8 [209-210]

Title SUB CYCLE, ITD's PROGRAM #4, 8 11/21/75 G.E. BAER

Step	#4 Key	Code	Display x	Display y	Display z	Step	#8 Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z
0 0	2					0 0	X←()	67				0					
1	4					1	−	34				1					
2	4					2	b	14	TDB			2					
3	FMT	42				3	↑	27				3					
4	⇑	56	WP			4	1					4					
5	↑	27				5	9					5					
6	3		3	WP		6	1					6					
7	IFX>Y	53				7	FMT	42				7					
8	2					8	⇑	56	ΔTDB	TDB		8					
9	b	14				9	+	33				9					
a	1		1			a	y→()	40				a					
b	↑	27				b	−	34				b					
c	2					c	b	14		TDB		c					
d	4					d	1					d					
1 0	4					1 0	9					0					
1	FMT	42				1	0					1					
2	y→()	40	244	WP		2	FMT	42				2					
3	1					3	⇑	56	ΔTDA			3					
4	2					4	↑	27				4					
5	8	10				5	X←()	67				5					
6	FMT	42				6	−	34				6					
7	⇑	56	TDA			7	a	13	TDA	ΔTDA		7					
8	X→()	23				8	+	33				8					
9	−	34				9	y→()	40				9					
a	a	13				a	−	34				a					
b	1					b	a	13		TDA		b					
c	2					c	FMT	42				c					
d	9	11				d	END	46				d					
2 0	FMT	42				0											
1	⇑	56	TDB			1											
2	X→()	23				2											
3	−	34				3											
4	b	14				4											
5	CLEAR	20				5											
6	2					6											
7	2					7											
8	0					8											
9	FMT	42				9											
a	y→()	40	220	0		a											
b	FMT	42				b											
c	END	46				c											
d						d											

Storage

f	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

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#5 [203] #6 [204-207]

Title SUB LTDAB,ΔTD PROGRAM #5,6 11/21/75 G. E. BKER

Step	#5 Key	Code	Display x	y	z
00	X←( )	67			
1	−	34			
2	b	14	TDB		
3	↑	27			
4	X←( )	67			
5	−	34			
6	a	13	TDA	TDB	
7	↑	27			
8	FMT	42			
9	END	46		TDA	TDB
a					
b					
c					
d					
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					

Step	#6 Key	Code	Display x	y	z
00	↓	25	TDA_D	TDB_D	
1	y→( )	40			
2	e	12			
3	X→( )	23			
4	f	15			
5	=				
6	=				
7	9	11			
8	FMT	42			
9	π	56	R		
a	↑	27			
b	6				
c	0		60	R	
d	×	36			
10	f	15	TDA_D		
1	↑	27			
2	X←( )	67			
3	−	34			
4	a	13	TDA	TDA_D	RX60
5	−	34		ΔTDA	RX60
6	↓	25			
7	X⇄Y	30	RX60	ΔTDA	
8	÷	35		ΔTDA	
9	1				
a	9				
b	0				
c	FMT	42			
d	y→( )	40	190	ΔTDA	RX60
20	e	12	TDB_D		
1	X⇄Y	30			
2	X←( )	67			
3	−	34			
4	b	14	TDB	TDB_D	RX60
5	−	34			
6	↓	25			
7	X⇄Y	30	RX60	ΔTDB	
8	÷	35		ΔTDB	
9	1				
a	9	11			
b	1				
c	FMT	42			
d	y→( )	40	191	ΔTDB	

Step	#6 Key	Code	Display x	y	z
30	e	12			
1	↑	27			
2	f	15			
3	↑	27			
4	FMT	42			
5	END	46			
6					
7					
8					
9					
a					
b					
c					
d					
0					
1					
2					
3					
4					
5					
6					
7					
8					
9					
a					
b					
c					
d					

Storage

	+	−
f	TDA_D	
e	TDB_D	
d		
c		
b		TDB
a		TDA
9		
8		
7		
6		
5		
4		
3		
2		
1		
0		

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[208] #9 [211]

Title FAKE TIME, SWITCH POSITION PROGRAM # 7, 9 G.E. BAER 11/21/75

Step	#7 Key	Code	Display x	Display y	Display z	Step	#9 Key	Code	Display x	Display y	Display z	Step	Key	Code	Display x	Display y	Display z
0	2					0	X← ( )	67				0					
1	4					1	—	34				1					
2	3					2	c	16				2					
3	FMT	42				3	FMT	42				3					
4	↑	56	T_{n-1}			4	END	46				4					
5	↑					5						5					
6	1					6						6					
7	1					7						7					
8	4					8						8					
9	+					9						9					
a	FMT					a						a					
b	END			TIME		b						b					
c						c						c					
d						d						d					
0						0						0					
1						1						1					
2						2						2					
3						3						3					
4						4						4					
5						5						5					
6						6						6					
7						7						7					
8						8						8					
9						9						9					
a						a						a					
b						b						b					
c						c						c					
d						d						d					
0						0											
1						1											
2						2											
3						3											
4						4											
5						5											
6						6											
7						7											
8						8											
9						9											
a						a											
b						b											
c						c											
d						d											

Storage

Register	Contents
f	
e	
d	
c	
b	
a	
9	
8	
7	
6	
5	
4	
3	
2	
1	
0	

TRACK PLOT

The track plot program is a modification of the navigation program. Section 5.4 of the main text explains how to change the navigation program to the track plot program.

Appendix B

WAY POINTS

The following pages contain the way point geographical locations and coordinates for passage downbound and upbound, in summer and winter.

Way Point Geographical Locations:
Downbound, Whitefish Bay to De Tour Passage, Summer

Chart	Way Point No.	Heading* (deg)	Distance* (mi)	Location
63	1	138.75	9.75	113°, 0.625 mi to Gros Cap Reefs Light
	2	138.75	6.375	138.75°, 0.125 mi to BC 35
	3	074.25	3.0	B 23 abeam
	4	059†	0.5	B 21 abeam
	5	031†	0.875	B 17 abeam
	6	053	2.375	203°, 0.25 mi to B 9
	7	076	2.125	Qk Fl W (cribs) abeam to starboard
	(Soo Locks)			
	8	088†	1.75	273°, 0.125 mi to FR on jetty
	9	119†	0.5	100°, 0.625 mi to Bayfield Dike Light
	10	109	1.125	303°, 0.5 mi to Bayfield Dike Light
62	11	153	3.375	157°, 0.25 mi to B 89
	12	143.5	1.5	274°, 0.125 mi to B 87
	13	159.75	6.0	Light 48 abeam
	14	181.5	4.375	BC 35 abeam
	15	144†	2.625	R 24 abeam
	16	168†	2.5	B 15 abeam
	17	128	5.0	318°, 0.45 mi to HB
61	18	128	4.375	B 21 abeam
	19	157†	0.75	113°, 0.18 to R 18
	20	187	3.875	056°, 0.23 to BW Mo(A)W
	21	115	4.5	180°, 0.25 mi to Fl G vis 6 St. M
	22	141	3.125	Watson Reefs Light abeam
	23	171	1.25	216°, 0.3 mi to Fl G (Frying Pan Island)
	24	180	3.25	308°, 0.75 mi to Fl W (De Tour Reef)

*Copied from charts to nearest eighth of a mile or fourth of a degree
†Scaled from charts

Way Point Geographical Locations:
Downbound, Whitefish Bay to De Tour Passage, Winter

Chart	Way Point No.	Heading* (deg)	Distance* (mi)	Location
63	31	138.75	---	138.75°, 0.125 mi to BC 35
	32	074.25	3.0	B 23 abeam
	33	059†	0.5	B 21 abeam
	34	031†	0.875	B 17 abeam
	35	053	2.375	203°, 0.25 mi to B 9
	36	076	2.125	Qk Fl W (cribs) abeam to starboard
	(Soo Locks)			
	37	088†	1.75	273°, 0.125 mi to FR on jetty
	38	119†	0.5	100°, 0.625 mi to Bayfield Dike Light
	39	109	1.125	303°, 0.5 mi to Bayfield Dike Light
62	40	153	3.375	157°, 0.25 mi to B 89
	41	143.5	1.75	030°, 0.125 mi to RN 86
	42	159.5	2.75	Light 80 abeam
	43	150	4.875	122°, 0.125 mi to B 59
	44	112	3.125	RN 42 abeam
	45	177	3.125	177°, 0.125 mi to FW (front Dark Hole Range)
	46	134.25	1.125	RN 20 abeam
	47	197	3.625	BC 7 abeam
	48	142	2.5	318°, 0.45 mi to HB
61	49	128	4.375	B 21 abeam
	50	157†	0.75	113°, 0.18 mi to R 18
	64	187	3.25	344°, 0.3 mi to B 13
	63	150	1.0	305°, 0.45 mi to BW Mo(A)W
	53	123†	3.75	180°, 0.25 mi to Fl G vis 6 St. M
	54	141	3.125	Watson Reefs Light abeam
	55	171	1.25	216°, 0.3 mi to Fl G (Frying Pan Is.)
	56	180	3.25	308°, 0.75 mi to Fl W (De Tour Reef)

*Copied from charts to nearest eighth of a mile or fourth of a degree

†Scaled from charts

Way Point Geographical Locations:
Upbound, De Tour Passage to Whitefish Bay, Summer

Chart	Way Point No.	Heading*	Distance* (mi)	Location
61	62	317	---	308°, 0.75 mi to Fl W (De Tour Reef)
	63	003	6.0	254°, 0.375 mi to Fl W (Pipe Is. Twins)
	64	295	6.625	305°, 0.45 mi to BW Mo(A)W
	65	330	1.0	344°, 0.3 mi to B 13
	66	007	3.125	113°, 0.18 mi to R 18
	67	337†	0.75	B 21 abeam
62	68	308	4.375	318°, 0.45 mi to HB
	69	322	2.5	BC 7 abeam
	70	017	3.625	RN 20 abeam
	71	314.25	1.125	177°, 0.25 mi to FW (front Dark Hole Range)
	72	357	3.125	RN 42 abeam
	73	292	3.125	122°, 0.25 mi to B 59
	74	330	4.875	Light 80 abeam
	75	339.5	2.75	030°, 0.125 mi to RN 86
	76	323.5	1.75	157°, 0.25 mi to B 89
63	77	333	3.375	303°, 0.5 mi to Bayfield Dike Light
	78	289	1.125	100°, 0.625 mi to Bayfield Dike Light
	79	299†	0.5	273°, 0.125 mi to FR on jetty
	(Soo Locks)			
	80	268†	1.75	Qk Fl W (cribs) abeam to starboard
	81	256	2.125	203°, 0.25 mi to B 9
	82	233	2.375	B 17 abeam
	83	211†	0.875	B 21 abeam
	84	239†	0.5	B 23 abeam
	85	254.25	3.0	138.75°, 0.125 mi to BC 35
	86	318.25	6.375	113°, 0.625 mi to Gros Cap Reefs Light

*Copied from charts to nearest eighth of a mile or fourth of a degree
†Scaled from charts

Way Point Geographical Locations:
Upbound, De Tour Passage to Whitefish Bay, Winter

Chart	Way Point No.	Heading*	Distance* (mi)	Location
61	91	0	---	216°, 0.3 mi to Fl G (Frying Pan Is.)
	92	351	1.25	Watson Reefs Light abeam
	93	321	3.125	180°, 0.25 mi to Fl G vis 6 St. M
	94	303†	3.75	305°, 0.45 mi to BW Mo(A)W
	95	330	1.0	344°, 0.3 mi to B 13
	96	007	3.125	113°, 0.18 mi to R 18
	97	337†	0.75	B 21 abeam
62	98	308	4.375	318°, 0.45 mi to HB
	99	322	2.5	BC 7 abeam
	100	017	3.625	RN 20 abeam
	101	314.25	1.125	177°, 0.25 mi to FW (front Dark Hole Range)
	102	357	3.125	RN 42 abeam
	103	292	3.125	122°, 0.25 mi to B 59
	104	330	4.875	Light 80 abeam
	105	339.5	2.75	030°, 0.125 mi to RN 86
	106	323.5	1.75	157°, 0.25 mi to B 89
63	107	333	3.375	303°, 0.5 mi to Bayfield Dike Light
	108	289	1.125	100°, 0.625 mi to Bayfield Dike Light
	109	299†	0.5	273°, 0.125 mi to FR on jetty
	(Soo Locks)			
	110	268†	1.75	Qk Fl W (cribs) abeam to starboard
	111	256	2.125	203°, 0.25 mi to B 9
	112	233	2.375	B 17 abeam
	113	211†	0.875	B 21 abeam
	114	239†	0.5	B 23 abeam
	115	254.25	3.0	138.75°, 0.125 mi to BC 35
	116	318.25	6.375	113°, 0.625 mi to Gros Cap Reef Light

*Copied from charts to nearest eighth of a mile or fourth of a degree
†Scaled from charts

Way Point Coordinates:
Downbound, Whitefish Bay to De Tour Passage, Summer

Way Point	TDX	TDY	TDZ	Calculated Heading (deg)	Chart Heading/ Distance‡ (deg/mi)
1	118* 11293366†	119 22353570	120 33081064	121 138.479	138.75/0
2	122 11197631	123 22346023	124 33118258	125 138.479	138.75/6.375
3	126 11213413	127 22351859	128 33127225	129 073.950	074.25/3.0
4	130 11216338	131 22353040	132 33128257	133 062.407	059/0.5
5	134 11221670	135 22355699	136 33125617	137 026.055	031/0.875
6	138 11236921	139 22362293	140 33129168	141 053.388	053/2.375
7	142 11248618	143 22366425	144 33141408	145 076.552	076/2.125
8	146 11258725	147 22369479	148 33156717	149 087.268	088/1.75
9	150 11260214	151 22369545	152 33162048	153 118.641	119/0.5
10	154 11264724	155 22370249	156 33173768	157 109.657	109/1.125
11	158 11261057	159 22364118	160 33202693	161 153.115	153/3.375
12	162 11261072	163 22361740	164 33215893	165 143.364	143.5/1.5
13	166 11243866	167 22341360	168 33255198	169 159.941	159.75/6.0
14	170 11212919	171 22317443	172 33266203	173 181.344	181.5/4.375
15	174 11208619	175 22305341	176 33281927	177 142.899	144/2.625
16	178 11193160	179 22288876	180 33288894	181 168.228	168/2.5
17	182 11200170	183 22262086	184 33316213	185 128.301	128/5.0
18	186 11206306	187 22235038	188 33332917	189 128.426	128/4.375
19	190 11203716	191 22228389	192 33334004	193 156.226	157/0.75
20	194 11178368	195 22200493	196 33330018	197 186.139	187/3.875
21	198 11195396	199 22171107	200 33345017	201 114.534	115/4.5
22	202 11195116	203 22144402	204 33349577	205 141.568	141/3.125
23	206 11191394	207 22135395	208 33349335	209 168.136	171/1.25
24	210 11178569	211 22116946	212 33346534	213 181.089	180/3.25
	214	215	216	217	
	218	219	220	221	

*Address
†Value to be inserted
‡Copied from charts to nearest eighth of a mile or fourth of a degree

Way Point Coordinates: Downbound, Whitefish Bay to De Tour Passage, Winter

Way Point	TDX	TDY	TDZ	Calculated Heading (deg)	Chart Heading/ Distance‡ (deg/mi)
31	118* 11197631†	119 22346023	120 33118258	121 138.479	138.75/0
32	122 11213413	123 22351859	124 33127225	125 073.950	074.25/3.0
33	126 11226338	127 22353040	128 33128257	129 062.407	059/0.5
34	130 11221670	131 22355699	132 33125617	133 026.055	031/0.875
35	134 11236921	135 22362293	136 33129168	137 053.388	053/2.375
36	138 11248618	139 22366425	140 33141408	141 076.552	076/2.125
37	142 11258725	143 22369479	144 33156717	145 087.268	088/1.75
38	146 11260214	147 22369545	148 33162048	149 118.641	119/0.5
39	150 11264724	151 22370249	152 33173768	153 109.657	109/1.125
40	154 11261057	155 22364118	156 33202693	157 153.115	153/3.375
41	158 11261053	159 22361310	160 33218016	161 143.417	143.5/1.75
42	162 11254112	163 22352837	164 33237764	165 159.095	159.5/2.75
43	166 11245182	167 22335784	168 33271569	169 150.560	150/4.875
44	170 11259491	171 22332013	172 33298706	173 112.098	112/3.125
45	174 11238201	175 22311165	176 33304011	177 176.304	177/3.125
46	178 11238298	179 22305547	180 33310444	181 134.653	134.25/1.125
47	182 11203221	183 22280168	184 33305313	185 196.472	197/3.625
48	186 11200170	187 22262086	188 33316213	189 141.083	142/2.5
49	190 11206306	191 22235038	192 33332917	193 128.486	128/4.375
50	194 11203716	195 22228389	196 33334004	197 157.226	157/0.75
51	198 11181922	199 22205206	200 33330425	201 187.241	187/3.25
52	202 11181543	203 22197821	204 33332313	205 144.861	150/1.0
53	206 11195396	207 22171107	208 33345017	209 116.345	123/3.75
54	210 11195116	211 22144402	212 33349577	213 141.568	141/3.125
55	214 11191394	215 22135395	216 33349335	217 168.136	171/1.25
56	218 11178569	219 22116946	220 33346534	221 180.869	180/3.25

*Address
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Way Point Coordinates: Upbound, De Tour Passage to Whitefish Bay, Summer

Way Point	TDX	TDY	TDZ	Calculated Heading (deg)	Chart Heading/ Distance‡ (deg/mi)
61	118* 11178569†	119 22116946	120 33346534	121 317	317/0
62	122 11178569	123 22116946	124 33346534	125 317	317/
63	126 11204783	127 22151419	128 33352902	129 003.829	003/6.0
64	130 11181543	131 22197821	132 33332313	133 294.937	295/6.675
65	134 11181922	135 22205206	136 33330425	137 324.861	330/1.0
66	138 11203716	139 22228389	140 33334004	141 007.241	007/3.125
67	142 11206306	143 22235038	144 33332917	145 337.226	337/0.75
68	146 11200170	147 22262086	148 33316213	149 308.486	308/4.375
69	150 11203221	151 22280168	152 33305313	153 321.803	322/2.5
70	154 11238298	155 22305547	156 33310444	157 016.472	017/3.625
71	158 11238201	159 22311165	160 33304011	161 314.653	314.25/1.125
72	162 11259491	163 22332013	164 33298706	165 356.304	357/3.125
73	166 11245182	167 22335784	168 33271569	169 292.098	292/3.125
74	170 11254112	171 22352837	172 33237764	173 330.560	333/4.875
75	174 11261053	175 22361310	176 33218016	177 339.095	339.5/2.75
76	178 11261057	179 22364118	180 33202693	181 323.417	323.5/1.75
77	182 11264724	183 22370249	184 33173768	185 333.115	333/3.375
78	186 11260214	187 22369545	188 33162048	189 289.657	289/1.125
79	190 11258725	191 22369479	192 33156717	193 298.641	299/0.5
80	194 11248618	195 22366425	196 33141408	197 267.268	268/1.75
81	198 11236921	199 22362293	200 33129168	201 256.552	256/2.125
82	202 11221670	203 22355699	204 33125617	205 233.388	233/2.375
83	206 11216338	207 22353040	208 33128257	209 206.055	211/0.875
84	210 11213413	211 22351859	212 33127225	213 242.407	239/0.5
85	214 11197631	215 22346023	216 33118258	217 253.950	254.25/3.0
86	218 11203366	219 22353570	220 33081064	221 318.479	318.25/6.375

*Address
†Value to be inserted
‡Copied from charts to nearest eighth of a mile or fourth of a degree

Way Point Coordinates:
Upbound, De Tour Passage to Whitefish Bay, Winter

Way Point	TDX	TDY	TDZ	Calculated Heading (deg)	Chart Heading/ Distance‡ (deg/mi)
91	118* 11191394†	119 22135395	120 33349335	121 001.089	000/0
92	122 11195116	123 22144402	124 33349577	125 348.136	351/1.25
93	126 11195396	127 22171107	128 33345017	129 321.568	321/3.125
94	130 11181543	131 22197821	132 33332313	133 296.345	303/3.75
95	134 11181922	135 22205206	136 33330425	137 324.861	330/1.0
96	138 11203716	139 22228389	140 33334004	141 007.341	007/3.125
97	142 11206306	143 22235038	144 33332917	145 337.226	337/0.75
98	146 11200170	147 22262086	148 33316213	149 308.486	308/4.375
99	150 11203221	151 22280168	152 33305313	153 321.083	322/2.5
100	154 11238298	155 22305547	156 33310444	157 016.472	017/3.675
101	158 11238201	159 22311165	160 33304011	161 314.653	314.25/1.125
102	162 11259491	163 22332013	164 33298706	165 356.304	357/3.125
103	166 11245182	167 22335784	168 33271569	169 292.098	292/3.125
104	170 11254112	171 22352837	172 33237764	173 330.560	330/4.875
105	174 11261053	175 22361310	176 33218016	177 339.095	339.5/2.75
106	178 11261057	179 22364118	180 33202693	181 323.417	323.5/1.75
107	182 11264724	183 22370249	184 33173768	185 333.115	333/3.375
108	186 11260214	187 22369545	188 33162048	189 289.657	289/1.125
109	190 11258725	191 22369479	192 33156717	193 298.641	299/0.5
110	194 11248618	195 22366425	196 33141408	197 267.268	268/1.75
111	198 11236921	199 22362293	200 33129168	201 256.552	256/2.125
112	202 11221670	203 22355699	204 33125617	205 233.388	233/2.375
113	206 11226338	207 22353040	208 33128257	209 206.055	211/0.875
114	210 11213413	211 22351859	212 33127225	213 242.407	239/0.5
115	214 11197631	215 22346023	216 33118258	217 253.950	254.25/3.0
116	218 11203366	219 22353570	220 33081064	221 318.479	318.25/6.375

*Address
†Value to be inserted
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Appendix C

SUMMARY OF DATA FILE

1/15/76 - 1/27/76	Eight plots of preliminary navigation using COGLAD.
1/20/76 - 1/22/76	Eight plots and seven listings of locations of random points along the edge of the river and channel.
1/17/76 - 1/21/76	Six plots and four listings of locations of way points.
1/14/76 - 1/27/76	15 plots of TD's and position jitter at dockside.
2/18/76 - 2/19/76	Nine plots of test results from Wildwood, NJ, using AN/SPN-45 receiver in COGLAD.
3/17/76	17 plots of test results from Wildwood, NJ, using DL-91 receivers in COGLAD.
3/27/76 - 3/28/76	11 plots of way points measured in preparation for demonstration.
4/7/76	Eight plots of navigation for demonstration.
5/18/76	Two plots of navigation around locks.
6/17/76 - 6/18/76	Four plots of dockside TD's and position jitter.
6/17/76 - 6/18/76	22 plots of navigation in the river.

Note: Prior to 3/17/76, the AN/SPN-45 receiver was used in COGLAD; after 3/17/76, the DL-91 receiver was used.